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THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. VIII.—*Seismoscopes and Seismological Investigations*; by T. C. MENDENHALL.*

SEISMOLOGY as a science, or at least as an observational and experimental science, may be said to be the product of the past three or four decades. It is true that before as well as during this period some important applications of the statistical method of investigation were made and the distribution of earthquakes in time and space was thoroughly studied. These investigations are of really high value, although they have generally resulted in the overthrow of certain hypotheses which were constantly appearing as to the correlation of these displays of seismic energy with other natural phenomena; so that while it may be said that little is yet known concerning the real nature and origin of earthquakes, much useful work has been done in the way of elimination and possibly a reduction of the number of unknown quantities involved.

The new phase which the science has assumed may perhaps be fitly described by saying that the modern seismologist studies an earthquake, rather than earthquakes. In fact this is one of a considerable group of problems primarily geological in their nature to which, in recent years dynamical principles and physical methods have been applied. The knowledge of first im-

* Read at the meeting of the National Academy of Sciences at New York Nov. 8th, 1887.

portance in regard to an earthquake is the knowledge of the nature and location of its origin and it is generally admitted that this can be obtained only through the study of individual instances. The natural method is to proceed from the known effect to the unknown cause, and for a time progress in seismology consisted largely in painstaking and laborious investigations of the destructive effects of earthquakes from which it was believed a knowledge of their ultimate origin might be deduced. Little in the way of experiment had been attempted and nothing was known of the really complex motion of the earth-particle when subjected to the influence of an earthquake wave. False assumptions were made with regard to this motion and erroneous and perplexing conclusions resulted. The great work of Mallet on the Neapolitan Earthquake, although of much importance in its day, and always a monument to his industry and devotion to the science, can not now be considered as of any great value as a solution of the problems involved.

The importance of earthquake measurements by means of specially constructed instruments was recognized by Mallet, however, and he undertook the design and construction of such instruments at an early date. The problem seemed at first easy, but investigation proved it to be of considerable difficulty. In a general review of the state of the science in his report to the British Association in 1858 Mallet says,* "twelve years ago the construction of seismometric instruments appeared a comparatively easy matter. It is only at a very recent period that experiments and observations as to the actual phenomena, the velocity and direction of the shock, etc., have begun to show the real difficulties of the subject." But even at this time Mallet failed to recognize the true nature of the disturbance produced by an earthquake, and the several seismometers which he devised, and which will be found described in the report already referred to, are practically of no value. One of them, which was extremely elaborate in its construction, he considered competent to furnish, from a single station, all of the elements necessary for the determination of the seismic focus. Another, the arrangement of two rows of cylinders of varying diameters in lines at right angles to each other, is probably the most widely known of all earthquake machines as it is described in many encyclopædic articles and treatises on Geology in which the subject is discussed. It may be said, however, that a more useless device has never been proposed.

A notable advance in our knowledge of the subject and particularly of instrumental Seismology has been made during the last half dozen years and it must be largely attributed to the

* On the Facts and Theory of Earthquake Phenomena—Report of the British Association, 1858.

organization and active operations of the Seismological Society of Japan. Earthquakes are there so frequent that a rare opportunity for their study is offered. A few foreigners temporarily residing in the country, together with a number of native scholars, joined in the prosecution of seismic investigations and in the establishment of the Society. Its published transactions, already filling ten volumes, contain nearly all of seismology that is in advance of the old methods. Progress has been made mostly in the direction of improvement in seismographs, and is, in a great degree, due to better methods for securing the very desirable "steady point" and to a recognition of correct dynamical principles in the construction of the instruments.

The well known horizontal pendulum or "bracket" seismographs of Ewing,* Gray,† Milne and others, have greatly increased our facilities for research and, in fact, have afforded about the only fairly reliable information concerning the real movement of the earth-particle.

Notwithstanding the comparative infrequency of earthquakes in the United States, many advantages for their study are offered here. Among others may be mentioned the following: the great extent of country which could be brought under one system of observations;—a generally intelligent population, furnishing a corps of willing and reliable observers:—the extensive system of telegraph lines; and, perhaps superior to every other, the wide distribution and almost universal use of "standard time" throughout the country. In consideration of these advantages and of the fact that certain portions of the country appear to be subject to occasional seismic disturbances, it has seemed desirable that an extended and well planned series of observations should be undertaken, and that seismology should not be in the future, as it has been in the past, a somewhat neglected science.

Among American geologists especially, there has always been great interest in the subject, and a good deal has been written concerning geological theories of earthquakes. Rockwood‡ has done excellent service in his publication of frequent catalogues of earthquakes in America, together with such information regarding them as could be incidentally gathered. But the first important step towards an elaborate and systematic study of earthquakes was taken a few years ago by the Director of the U. S. Geological Survey in establishing what has been known as the "Earthquake Commission" The work of this body, during its existence, consisted mainly in the discussion of methods of observation, together with the preliminary arrange-

* Trans. Seis. Society of Japan, vol. ii.
† Trans. Seis. Society of Japan, vol. iii.
‡ This Journal, from 1872 to the present time.

ment of a plan of attack and the selection of the most desirable regions for the inauguration of the work. A scale of intensities was adopted and a series of questions formulated which were printed in the form of circulars for distribution among the intelligent observers of any disturbance. These circulars were subsequently made use of by Captain Dutton, who had the general direction of the work, and considerable information concerning several earthquakes has been obtained. The Charleston earthquake of 1886, renewed and greatly increased the interest in the problem. It was thoroughly investigated by Dutton and Hayden and their report* upon it, presented to the National Academy of Sciences in April, 1887, is of great value. As complete, perhaps, as was possible under the circumstances, it serves to emphasize the necessity for the use of seismic apparatus, and causes extreme regret that instruments had not been previously perfected and put in operation.

I think it can be said that America has made at least one really valuable contribution to the Science of Seismology. I refer to the approximate determination of the velocity with which earthquake waves are transmitted through the crust of the earth. The unexampled opportunities offered in the explosions at Hell Gate and Flood Rock† were utilized for this purpose, with the unexpected and surprising result of a rate of transmission vastly greater than that previously obtained by European and Oriental Seismologists, and generally accepted as fairly accurate. The reduction of fairly accurate time observations made on the occasion of the Charleston Earthquake,‡ served to confirm this conclusion and a speed of several thousands instead of a few hundreds of meters per second must now be admitted. Although these results are more nearly in accord with the theory of wave transmission, future determinations of velocity will be awaited with great interest, and all processes employed must be carefully scrutinized.

Before considering a plan for the inauguration and maintenance of an extensive series of seismological observations, it will be well to inquire what knowledge is most desirable in the interests of geological investigation. This is a question for geologists to answer; but I venture the assertion that in the present state of our knowledge of seismology, it is most desirable, in the case of any given earthquake, to be able to fix the seismic vertical, or the epicentrum; to ascertain the depth at which the initial disturbance occurred; and to measure the velocity with which the resulting waves are transmitted. If these can be accurately determined for different earthquakes, under varying conditions, some light may be

* Science, May 20th, 1887.

† Science, Jan. 8th, 1886.

‡ Science, May 20th, 1887; see also this Journal, Jan., 1888, pp. 1–15.

thrown upon their ultimate origin and the magnitude of the energy involved, while the study of velocities of transmission, co-seismal and iso-seismal lines, may afford valuable information concerning the nature and condition of the rocks within the disturbed area. Admitting the greater importance of a knowledge of these facts it follows that time measurements should first receive attention, and that the seismic chronograph is the instrument to be used.

The seismograph or seismometer is designed primarily for the purpose of recording or measuring the actual motion of that part of the earth to which the instrument is attached during the transit of one or many waves. In reality this motion is extremely complex. Undoubtedly the emerging wave is modified very greatly in its character by the lack of homogeneity in the material through which it last travels, as well as by the fact that this material differs immensely in elasticity and density from that in which it has in the main existed. For this reason it is believed that however accurately the motion may be resolved into three components at right angles to each other by a perfectly operating seismograph, but little information would be afforded as to the position of the origin, or the amplitude of vibration and amount of acceleration of any point in the earth, other than that at which the instrument is located. It is clear, however, that while these considerations may seriously affect the integrity of the record of a seismograph, they will have little influence upon the actual transmissive time, that is to say, while the character of a wave may be greatly altered upon emergence into a non-compacted, non-homogeneous material, the time of its arrival at a given point cannot be greatly altered, even if its velocity in this material is much less or greater than the mean, for the reason that it is subjected to this modifying influence for a comparatively brief period. It is true that the seismograph, in addition to registering the motion of the earth particle, may and generally does record the epoch of the passage of a wave, and it affords the advantage of distinguishing one wave from another. If only very short distances are used for the determination of velocities this would be of decided value, were it not that experience* seems to prove that what is the maximum wave at one point may not be the maximum at other points very near, so that it is by no means certain that a particular wave can be identified at different stations, even if they are not widely separated. These considerations, together with the very great expense of seismographic equipment and the greater difficulty of maintaining them in constant working order in a country where earthquakes are infrequent, compel the admission that

* Milne, in Trans. Seis. Soc. of Japan, vol. x.

the simple seismoscope, with a time-taking attachment, is far more likely to furnish valuable information.

Seismoscopes.

A good seismoscope should possess some if not all of the following characteristics:—

It should be simple, inexpensive and not liable to become inoperative through long periods of rest;

It should be capable of adjustment to varying degrees of sensitiveness;

The adjustment of different instruments to nearly the same degree of sensitiveness should be possible;

Its equilibrium should be unstable; that is, when once disturbed it should not "reset" itself;

It should not be liable to register phenomena other than actual movements of the earth upon which it rests.

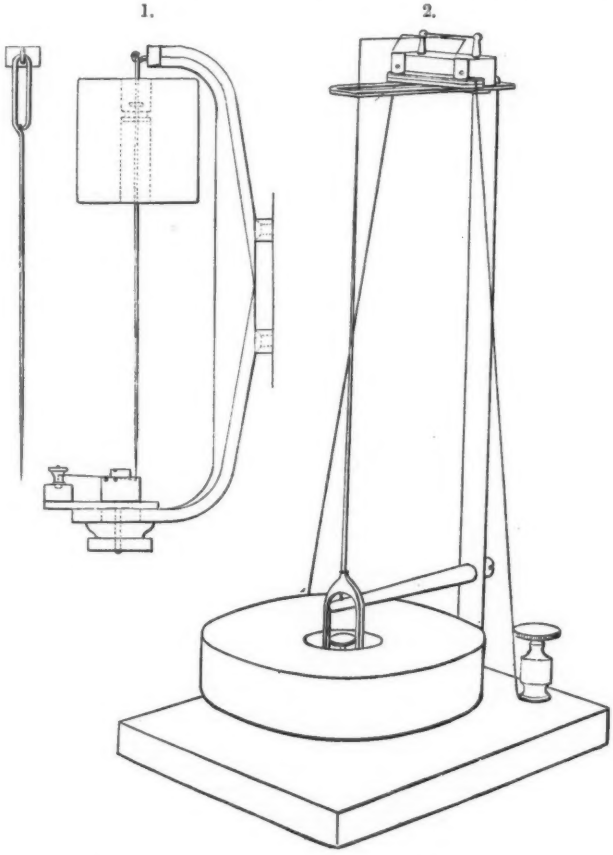
While much has been done and notable advances have been made in the construction of seismographs with a view to the determination of the character of the motion of the earth particle, it does not appear that a seismoscope satisfying these conditions has yet been described or extensively used, although an infinite variety of instruments bearing the name have been devised. If whatever is done in the near future is likely to be done through the use of the time-registering apparatus, and this, I believe, is the opinion of the majority of the members of the earthquake Commission assembled upon the invitation of the Director of the Geological Survey, the subject becomes one of considerable importance, and a recognition of this fact has resulted in the suggestion of several new forms of seismoscopes within the last two or three years, a few of which have been actually constructed and tested. The first of them, and the only one as far as I know which has been used to register the occurrence of an earthquake in this country, was designed in the Physical Laboratory of the Signal Office at Washington. While others contributed suggestions as to certain details, the general form of the instrument is due to Junior Professor C. F. Marvin, of the office of the Chief Signal Officer.*

It is shown in figure 1 and a little explanation will make its operation clear.

An iron cylinder weighing three or four pounds has a cylindrical hole of about 2^{cm} in diameter, bored through concentric with its axis. At a point a little distant from the

*The first practical use of an instrument of this type was at the Flood Rock Explosion in October, 1885. It was placed by direction of the writer at the nearest point of observation, on Ward's Island. Its performance was entirely satisfactory. See Science, Oct. 16, 1885. An instrument somewhat similar in design with a very imperfect contact-making device was suggested by Milne. See Trans. Seis. Soc. Japan, vol. iii.

center of gravity this hole is suddenly diminished in diameter by a small amount, affording a shoulder against which rests a cross piece filling symmetrically only a part of the opening and carrying at its center, which is on the axis of the cylinder, a fine steel point. This point rests in a small depression on the inner side of a link, to which is attached a long steel needle as



shown in the cut. The upper end of the link hangs upon a hook made of wire of the same diameter and rigidly attached to the supporting frame of the instrument which is of iron. By this arrangement for the suspension of the heavy mass, the link with its needle projecting downwards, has considerable freedom of motion in all azimuths, with little frictional resist-

ance, and for slight movements the pivotal point within the cylinder may be regarded as fixed. Rotation takes place about this point and the motion of the earth, which is that of the hook upon which the link is suspended, is magnified at the point of the needle as many times as the ratio of the length of the needle to that of the link. A small and very light lever has its short arm bent upward, and is so adjusted that when the instrument is "set," the upper end, ground to a fine point, rests against the pointed end of the long needle. The longer and heavier arm of this lever terminates in a platinum fork, the prongs of which are vertically above two small mercury cups forming terminals of the electric circuit.

The operation of the instrument is simple. A very slight movement of the point of suspension is magnified at the needle point; the short arm of the lever is released and the fork drops, closing the circuit. Different degrees of sensitiveness are obtained by grinding the abutting points to greater or less dimensions.

A seismoscope of great simplicity of design, and offering many advantages, is one originally due to Milne,* and more recently with slight modifications, experimented with by Hayden and Hallock, of the U. S. Geological Survey, by whom it was also, I believe, independently invented. It belongs to the family of liquid seismoscopes, of which many varieties have appeared, notably several devised and used by Palmieri. In all previous forms, however, the action utilized was the movement of the whole mass of liquid in relation to the containing vessel, while in this, advantage is taken of the well known fact that waves are, in general, produced upon the surface of a mass of liquid when it is subjected to a sudden disturbance. In a cylindrical vessel these waves run from circumference to center, at which point the liquid is sensibly elevated for an instant, and through this elevation an electric circuit may be momentarily closed. Mercury is the liquid used, and it is placed in a small cylindrical iron box, through the cover of which a pointed screw with a large divided head runs. The point of the screw, which is of platinum, may be brought extremely near the surface of the mercury, its position and distance being known by means of the divisions on the head. A slight jar generates a series of waves, the elevation at the center completes the circuit through the properly insulated screw. The tendency of the mercury to become oxidized or dirty upon the surface so as to become inoperative was overcome by the use of a small platinum float, a device previously employed for measuring the height of the mercury in the cistern of a barometer by electrical contact. A

* Trans. Seis. Soc. Japan, vol. iii.

simple arrangement for keeping this float in position is employed and the real contact is between two platinum surfaces, being thus much more desirable and lasting.

Several other forms of seismoscopes have been suggested and tried with more or less success. One of these is a modification of the well known Zöllner's horizontal pendulum, the extreme sensitiveness to change in level of which has been so well shown by Professor Rood.* It is easy to arrange this so that an electric circuit is closed when a disturbance occurs; and, although its greatest sensitiveness is for disturbance in one plane it is generally sufficiently delicate to respond to very feeble motions in all azimuths.

I have recently modified the instrument first described, reducing its dimensions and cost, and greatly increasing the ease with which it is adjusted and "set." The alteration consists principally in extending the multiplying needle upward instead of downward. This brings the circuit-closing part of the apparatus above, where it is open to inspection and convenient for adjustment. The supporting frame rests upon a square or triangular base, and can be placed upon any convenient pier or table, instead of necessarily being screwed to a vertical support as in the earlier form. The latter plan was adopted with a view to fastening the instrument to a post driven in the earth, but it has been found inconvenient in practice, and it will gen erally be better to rest it upon the top of the post, if one is used, or upon a stone imbedded in the earth, or upon a bracket shelf attached to a foundation wall.

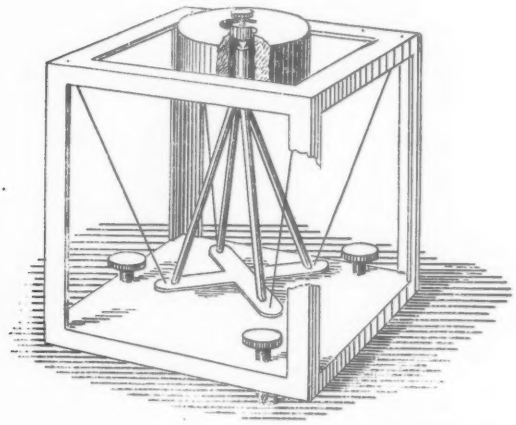
The new form of the instrument is conveniently covered by an ordinary glass shade to protect it from dust and disturbance by air currents. An improvement is made in the arrangement for adjusting the position of the circuit closer, which is held to the table upon which it rests by means of a spiral spring, so that while it moves freely upon the application of a slight pressure it is sufficiently firm to resist accidental disturbances. The new form will be readily understood by examination of fig. 2 (p. 103.)

Any mechanical device by means of which a temporarily "steady point" is provided may be utilized as a seismoscope. The horizontal pendulum, first suggested by Chaplin and utilized by Ewing in his seismograph, satisfies the requirements, except that its sensitiveness exists in only one plane. The use of some form of link motion for an astatic suspension was suggested by Professor West a few years ago, at a meeting of the Seismological Society of Japan.† It is clear that an ideal arrangement would be the Peaucellier linkage for straight line motion in a horizontal plane. But it is difficult if not impossible to avoid

* This Journal, III, June, 1875. † Trans. Seis. Soc. Japan, vol. vi.

an amount of friction which would be fatal. Ewing * has suggested the use of some form of linkage in which only ties should be used, so that flexible cords could be substituted for rigid bars. No rigorously straight-line motion is susceptible of this construction, but several close approximations may be utilized. An approximation is all that is required in a seismoscope, but it must possess freedom of motion in all azimuths. Professor Ames, of the Rose Polytechnic Institute, has devised a form consisting of a combination of two linkages of the form invented by Roberts. By arranging these in planes at right angles to each other, freedom of motion in any azimuth is secured. A heavy mass is pivoted at the tracing point and friction may be reduced to a minimum by the use of flexible cords, fine wires, or by pivoting light rigid links. The suspension is approximately astatic, but sufficiently so for seismoscopic uses, and perhaps for seismographs—It is shown in figure 3.

3.



A number of trials with several of these seismoscopes under different varieties of disturbance show that all are not equally sensitive to the same disturbance, however delicately they may be adjusted. The mercury seismoscope is peculiarly sensitive to disturbances produced by a slight jar of the table or support upon which it rests. In this case the vibrations are generally very rapid, probably from ten to fifty or more per second. It may readily be adjusted to respond to extremely slight tremors and besides it apparently affords the advantage of being set at any time to a definite degree of sensitiveness. With the two

* Memoirs of the Science Dept., Tokyo Daigaku, No. 9.

or three instruments of this class upon which I have experimented, this theoretical advantage is not realized in practice. The distance between the two platinum surfaces is so extremely small, when the instrument is sensitively adjusted, that very trifling and generally unknown causes will considerably modify the position of the divided head when contact occurs. The setting of the instrument is therefore a matter of great uncertainty.

This instrument possesses what at first appears to be an advantage, in that it is "self-setting;" but a reference to what has gone before will show that this is not considered a desirable feature of a seismoscope. In fact, it is very undesirable in my judgment, except where devices of a special character are made use of for securing time records. If the epoch is established by stopping or starting a clock or by Milne's printing device, a self-setting instrument would be objectionable. If the record is made upon the revolving drum of a chronograph, or on a continuously moving strip of paper, this form of seismoscope might fix the time of all sensible movements during the disturbance, and might, indeed, play the part of a seismometer in some degree by distinguishing the more violent motions. But it would be likely to fail in this respect, as well as in its general performance as a seismoscope, owing to the peculiarity already referred to. To vibrations of moderately long period it does not promptly respond. Earthquakes seldom, if ever, begin with a sharp and sudden movement. The maximum vibration is nearly always preceded by several of less amplitude and nearly the same period, which are themselves preceded by oscillations of extremely small amplitude but of great frequency. The intensity of these preliminary tremors is not, in general, sufficient to cause a mercury seismoscope to act, and to the succeeding movements of greater amplitude but longer period, (often as long as one second) it is not sensitive. Further experiment and investigation is needed, however, to determine the relative merits of these and other instruments.

Time Apparatus.

Various methods of time-registration have been made use of, and most of them are generally well known. A choice among them must depend largely on the probable frequency of earthquake phenomena. In Japan and some other parts of the world rarely more than a few days pass without a sensible disturbance.

A continuously operating chronograph would be desirable and profitable under such circumstances and various modifications of the ordinary astronomical chronograph will at once suggest themselves as suitable for this work. When an earth-

quake is a rare phenomenon, years instead of days elapsing between two successive disturbances, all appliances for their observation must be of the utmost simplicity of construction consistent with certainty and accuracy of performance. A fairly good clock is a necessity and that being provided it remains to determine how it may be used in recording the instant of disturbance. One of three different schemes may be adopted: a running clock may be stopped; a clock at rest with hands set in a known position may be started, or the position of the hands may be registered without interfering with the going of the clock. Either of these can be easily accomplished through the instrumentality of the electric circuit closed by the effect of the disturbance on the seismoscope. The simplest method is that of stopping or starting the clock, and considerable difference of opinion has existed as to the relative merits of these two processes. It will be seen at once that the plan of starting a clock from rest in a known position would have many advantages, and one of them is certainly of great importance. It is that after the happening of the earthquake the started clock can be allowed to run until a comparison with some standard time is possible and if necessary its rate may be determined, so that the exact epoch of the disturbance can be ascertained with considerable accuracy. On the other hand, if a clock be stopped our knowledge of the exact time of the occurrence will depend on our knowledge of its error at the time of stopping, which can only be known through previous observations of error and clock rate. Thus it will appear that if the method of clock stopping is to be resorted to, the clock must be under constant surveillance and frequent comparisons must be made with some standard time. The clock-starting method is also open to some rather serious objections. A clock which has been at rest for months or even years is hardly likely to be constant in its rate during the first few hours after starting. This objection can be in a great degree removed, however, by carrying out suggestions to be given later. Another, and more important, is that the record is liable to be lost entirely through the subsequent stopping of the clock by the violence of the earthquake. The clock-stopping method is not open to this objection as it is difficult to imagine the starting of a clock by an earthquake, particularly if the pendulum is held somewhat firmly by the stopping apparatus. The third plan, that of registering the position of the hands of the clock at the moment of closing the circuit without interfering in any way with the movement of the clock combines many of the advantages of both the others, but has the disadvantage of being more complicated and difficult to accomplish. It is easy to expose for an instant a quick photographic plate, upon which an image of the clock face is projected, but

we at once meet with the difficulty of properly illuminating the face at night.

Among other methods which have been proposed, probably the most simple is that of Milne,* which consists in placing small pieces of cork, coated with an oily ink, upon the extremities of the hands of the clock against which a paper or card board ring is pressed by electro-mechanical devices, put in operation by the closing of the circuit at the seismoscope. After an instant of pressure the ring is withdrawn, bearing a printed record of the position of the hands of the clock. This allows the determination of the error and rate of the clock either before or after the earthquake or both, and should the clock be stopped by a violent shock, the time record is not lost. These advantages will undoubtedly lead to the invention of simple and sure methods by means of which this printed record may be obtained. For stopping a clock, Milne† has used a thin piece of board in which notches are cut in one of which the pendulum is caught at the moment of the disturbance. This method is likely to allow and sometimes to cause considerable subsequent swaying of the pendulum and I have preferred to use simply a strip of brass, curved to an arc of the circle whose radius is the pendulum. This lies always nearly touching the pendulum and is slightly lifted when the circuit is closed so as to arrest the pendulum. The brass strip is attached to the movable armature of a common telegraph sounder secured to the side of the clock case. The circuit remaining closed after the action of the seismoscope the pendulum is held in its place.

Application.

Two seismic stations with time-taking apparatus have been in operation in this country for nearly a year. The first was established in the Physical Laboratory of the Signal Office in Washington shortly after the occurrence of the Charleston Earthquake, and the second, at the Rose Polytechnic Institute, Terre Haute, Ind., was put in operation in January, 1887. Both are equipped with seismoscopes similar to that described and shown in fig. 1 and with clocks known as "Regulator No. 2," made by the Seth Thomas Co. These clocks were selected on account of their cheapness and their really excellent performance as time keepers. The stopping apparatus is of the simple form already described, and an ordinary vibrating electric bell with battery is connected with it so that a continuous alarm is maintained from the time of the disturbance of the seismoscope.

* Trans. Seis. Soc. Japan, vol. iv. † Trans. Seis. Soc. Japan, vol. iii.

Since their installation these instruments have recorded as follows:—

At Washington.—From Oct. 6th, 1886, to Nov. 4th, 1887.

Date.	Time, (75th Mer.) h.	m.	sec.	Remarks.
October 22, 1886	2	46	14 p. m.	Felt generally in the vicinity.
November 5, 1886	12	27	14 p. m.	
February 23, 1887	7	33	0 a. m.	Possibly related to the great Italian earthquake of that time. From the condition of the instrument before and after the time of the record it was thought to be reasonably certain that it was due to a true seismic disturbance.

At Terre Haute.—From Jan. 18th, to Oct. 26th, 1887.

Date.	Time, 90th Mer. h.	m.	sec.	Remarks.
February 3d	10	27	35 a. m.	Shocks in Italy, Feb. 3.
February 6th	4	15	6 a. m.	Shocks in Ind., Ill., Ky., and Mo.
February 10th	11	22	27 a. m.	Papers reported shock at Jasper, Ind., but not verified.
May 6th	7	45	22 a. m.	May 3d and 4th, general in Mexico and from Texas to Cal. 150 lives lost at Babispe in Sonora, Mex., also many topographical changes.
May 10th	6	1	34 p. m.	Shocks in mountains daily, May 12 and 13, shocks in S. C., Cal. and Arizona, May 19 and 20 in Europe. May 30 and 31, in Mexico.
May 24th	10	3	33 a. m.	Shocks felt in Ind., Ill., Ky., and Tenn., and in Equador, S. A.
August 2d	12	35	43 a. m.	
October 22d	6	6	35 a. m.	

Plan of Campaign.

In determining upon a systematic plan for the instrumental study of earthquake phenomena, some consideration of the foregoing remarks seems to be demanded, and some useful conclusions may be drawn from the brief experience already had.

In the first place, it is claimed that time observations are of the first importance and that under the circumstances such only should be undertaken. It is believed that the reasons briefly, and in some degree imperfectly, presented in the foregoing dis-

cussion, are sufficient to establish the claim. Seismoscopes, with the accompanying clocks, should be the only instrument used, and these should be, as far as possible, of the same type. Before the adoption of any one of several different species available, a careful study of them should be made, all being tested under similar conditions and these conditions should resemble as closely as possible those under which the instrument is expected to work. As seismic phenomena are here too infrequent to admit of such preliminary test or calibration, means must be provided for imitating at will the motion of a point upon the surface of the earth. Such an arrangement would also be useful in testing seismographs and the validity of their records.

For this purpose what may be called a "seismic table" has been designed. It consists essentially of a horizontal surface, large enough to furnish room for two or three seismoscopes or seismographs, and which by suitable mechanism may be given a vibratory motion in either one or all of three directions at right angles to each other, two of these motions being in a horizontal plane. The vibrations are all derived from a single piece rotating with a uniform angular velocity, and all are on a close approximation to simple harmonic motion. By a simple device their amplitude may be varied at will and without arresting the movement, from zero to a prescribed limit. Another mechanism enables the operator to vary the frequency of vibration from zero to any desired number per second. The machine is to rest upon a solid foundation and power is to be drawn from a steam or gas engine. At any moment, the amplitude and frequency of vibrations along any of the three components will be shown by suitably arranged indices. The disturbance to which a seismoscope is subjected can generally be resolved into approximately simple harmonic motions along these axes, and as the period and amplitude of vibration for earthquakes of moderate intensity are now tolerably well-known, through the investigations of Japanese earthquakes by Ewing, Milne, Gray and Sekiya, it will be possible to reproduce their movements with considerable accuracy and with such variations as to intensity as to satisfy every demand in testing seismic instruments. In this way it can be determined to what particular species of vibration a seismoscope is sensitive; whether the same seismoscope can be repeatedly set to the same degree of sensitiveness, and whether several different instruments can be made to agree in this respect. In addition to its great value as affording a means of testing and comparing instruments, it is believed that such an apparatus may be useful in studying certain observed effects of earthquakes upon simple structures. By submitting small but

dynamically similar models of such structures to differently compounded vibrations and studying the results, some light may be thrown upon the confusing and often contradictory phenomena of actual earthquakes.

Assuming that a satisfactory form of seismoscope has been selected by subjecting all proposed or submitted to the test of the seismic table, it is important to consider next their distribution and use. As it is very desirable that they should be as numerous as possible, and as the cost of the equipment of a station is of great practical moment, it may be stated that the whole outfit for a single station, including clock, seismoscope, battery and all, need not cost more than twenty-five dollars, and it is hoped that a sum considerably less than that amount may be found sufficient. In selecting stations it is of the utmost importance that the question of accurate time should be first considered. Standard time signals from one observatory or another are now distributed so generally over the whole country, that in any considerable town no difficulty will be found in determining the clock error and rate, provided that the apparatus is in the hands of a suitable person. It is likely that in many instances jewelers or watch makers, who receive time signals daily will be willing to undertake the care of a seismic station. The seismoscope may be mounted upon a bracket secured to the stone or brick foundation of a building, in the cellar or basement, while the clock should be placed where it will be often seen, or where it may be of real service as a time-keeper to the observer. The use of an electric alarm, while not a necessity, is very desirable, as through its action attention is immediately called to the disturbance, and even a second or two of warning might enable many interesting observations of phenomena which would otherwise escape the observer.

I have found it very useful to provide for regular tests of the apparatus on the first of each month. An artificial disturbance near the seismoscope takes the place of a real earthquake and the operation of the bell-ringing, clock-stopping apparatus is observed, the clock error and rate applied, and in fact everything is done as if a real earthquake had occurred. This will enable the observer to detect any fault in his arrangements and will serve in a great degree to maintain his interest and sustain his patience through months or years of waiting for an actual record. Blanks should be furnished on which the results of these tests may be recorded and forwarded to the person in charge of the whole system of observations. Many other details might be referred to, but they belong rather to a code of instructions for observers. There is one matter connected with the establishment of stations, however, which experience has shown to be important.

The records of a seismic station, even when equipped in the best possible manner, will be unquestionably affected by what may be called "accidental errors." That is to say, it is believed that the best of seismoscopes will fail to satisfy entirely the conditions given above and will occasionally "go off" when there has been no real seismic disturbance. This may be due to a variety of causes, among which may be mentioned: changes in the position, level, etc., of the support of the instrument, through a slow movement of the wall or pier to which it may be attached; occasional movement of heavy bodies in close proximity to the instrument; very violent winds which may disturb the foundation of the building in which it is placed, etc. It is often difficult to distinguish a false alarm thus given from a true seismic disturbance and in the records of the seismoscopes at Washington and Terre Haute already given, two or three doubtful instances occur.

When the earthquake is sufficiently violent to be detected without instrumental aid, confirmatory evidence is furnished; but one of the principal objects in making use of instruments is to detect movements which would otherwise pass unnoticed and to extend the range of observation of the more violent far beyond what it can be at present. As an illustration of the great importance of being able to know a genuine record I may invite attention to one of the records made at Washington a few hours later than the Italian earthquake of last year. The epoch of the disturbance is such that there is nothing unreasonable in supposing that it was really a wave which had been transmitted across the sea or through the crust of the earth. Interesting as this fact would be, it would be rash to make such an assumption in view of the possibility of a purely accidental disturbance of the instrument.

A very similar state of affairs exists in connection with one of the records of the Terre Haute seismoscope. Had there been several instruments along the Atlantic coast they might have confirmed or confuted the record made at Washington. It is highly probable, however, that disturbances frequently occur which do not affect large areas. In arranging for the systematic observation of phenomena so rare and so uncertain as to time and place as earthquakes, it will hardly be possible to place stations sufficiently near each other to insure the detection of these minor movements, although they are for many reasons of prime importance. With the possibility of accidental disturbance and with seismoscopes somewhat widely separated, it would seem impossible ever to certainly detect such minor movements in the surface of the earth. There is a remedy, however, and it lies in the precaution, the truth of which ex-

perience has forced upon me, that *wherever there is one seismoscope there must be two.* That is to say, when any locality is selected as a suitable place for a seismic station two complete stations must be established; separated sufficiently so as not to be liable to the same accidental disturbances but near enough to render it reasonably certain that a real seismic disturbance which affects one will also affect the other. If separated by a distance of from a few hundred feet to a quarter or half a mile, the necessary conditions would be satisfied. Two such stations ought to sensibly agree as to the exact time of any disturbance and not only would they enable the observers to distinguish accidental or false alarms, but they would afford excellent checks upon each other on the occasion of a genuine record.

It is hardly necessary to refer to the interesting and important results which would almost certainly come from the organization of one hundred or even fifty such stations wisely distributed, at first over those sections of the country known to be most subjected to earthquakes. On the hypothesis of transmission through a homogeneous, elastic medium, records at less than a half dozen stations will suffice to determine the velocity of transmission, and the coördinates of the origin of the disturbance. Although in the case of the earth this hypothesis is not tenable, it is an approximation to the truth, and there can be no doubt that the mean of a number of such determinations, based upon different groups of observations would have considerable weight in the discussion of the dynamics of the problem.

I think it will be generally admitted that the management and direction of an investigation so extensive as the territory involved could only be successfully carried out by the government; and that the Director of the Geological Survey, of whose disposition in the matter there can be no doubt, should be furnished by Congress with the authority and material for its accomplishment.

ART. IX.—*On a new Petrographical Microscope of American Manufacture;* by GEORGE H. WILLIAMS.

THE importance of the microscope in geological investigations—particularly in the domain of the crystalline rocks—is now universally recognized, even by those geologists who do not themselves employ it. The light already shed upon some of the darkest and most intricate problems by recent petrographical methods, uncertain though it sometimes be, is full of promise for the future. Geology is reaping almost as great

benefits from the application of the microscope as her sister sciences, biology and medicine; and there seems to be no good reason why this instrument should not be made of as much educational value in her field as in theirs.

Not all who study the natural sciences are able or care to become original investigators. The scientific training, however, possesses for every one certain peculiar advantages, and the organic sciences have not been slow to appreciate how valuable a factor in such a training the microscope may be made. Five years of practical experience have convinced the writer that the microscope in geology may, with as great success, be employed for purely educational purposes.

If then the microscope be of such use in geology, both as a means of research and as an educational discipline, the production of instruments especially designed for rock-study becomes a matter of importance. Such a demand has for some time past been met, with varying success, by several Continental manufacturers; but, owing to the limited interest in microgeology on this side of the Atlantic, the attempts of American makers to supply petrographical microscopes have hitherto been wholly inadequate.

The advantages to the constantly increasing number of petrographical students in America, of a suitable instrument of home manufacture, are too apparent to need enumeration. Indeed, the actual demand for such an instrument has been so often and so urgently forced upon the writer's attention, that, at his request, the well-known Bausch and Lomb Optical Company of Rochester, N. Y., undertook the construction of a purely petrographical stand which should satisfy all the demands for mineral and rock study and at the same time come within the means of geological students. Each essential point was designated by the writer and has been elaborated by the manufacturer in the simplest and most inexpensive manner consistent with satisfactory results. The instrument in its present shape, though it may be subject to further improvements, offers at a reasonable price ($135.00) a complete petrographical and mineralogical microscope of excellent workmanship, possessing all essential features, and several advantages (such as a sliding analyzer and mechanical stage) to be secured only on the more expensive European stands.

It has been thought that a figure and description of this microscope would prove of interest to all whose attention is devoted to geology, whether as teachers or as investigators.

The accompanying cut shows the instrument constructed upon what is known as the Bausch and Lomb "*Model Stand.*" (See Bausch and Lomb Illustrated Catalogue for 1887, pp. 15.) This has a frame of japanned iron, with brass tube, stage and

mirror-bar. It was selected in order to reduce the total expense as much as possible, but all the petrographical appliances may be adapted to any of the brass stands of this firm, if desired, with a proportionate increase in expense.

(One-third natural size.)

The screw supporting the arm between the pillars allows the instrument to be inclined at any angle. The main tube is provided with a cloth lining into which the draw-tube carrying the ocular, is fitted. There is a coarse adjustment by rack and pinion and a fine adjustment by a micrometer screw. The mirror is both flat and concave and the mirror-bar adjustable.

Coming now to the peculiarly petrographical features, we have the lower nicol-prism or polarizer enclosed in a cylindrical metal box, both ends of which are protected by glass. This box is capable of a complete revolution and is provided

with a graduated silvered circle and index. It is held by a cylindrical frame in which it may be raised or depressed at will by a rack and pinion movement. This frame is attached to the under side of the stage by a swinging arm, so that the whole polarizing apparatus may be thrown to one side if desired. A strong compound lens may be screwed upon the upper end of the polarizer whenever strong illumination or converged polarized light are needed.

The circular stage (9·5 cm. in diameter) is provided with a beveled silvered edge, graduated to degrees. Upon this is mounted for smooth and concentric revolution the admirable mechanical stage, known in the manufacturer's catalogue as No. 1052. This carries an index for reading the graduated circle, and is also provided with silvered graduations for its two rectangular movements, whereby any point in a section can be readily located. The upper sliding bar which carries the object has been shortened so as to be only flush with the revolving stage when pushed to its extreme limit on either side. With this, square or short rectangular glasses must be used for mounting which will avoid any interference with the revolution of the stage.

Into the nose-piece, just above the objective, is an opening intended to receive the four following accessories, each mounted in a separate brass frame: (1) a Bertrand lens for magnifying the interference figures; (2) a quarter-undulation mica-plate; (3) a quartz wedge; (4) a Klein quartz-plate or a gypsum plate with red of the first order.

The centering of the various objectives is secured by two screws having motions at right angles to each other.

The upper Nicol-prism or analyzer is inserted in the tube in order to avoid the diminishing of the size of the field which is unavoidable when the prism is placed over the ocular as a cap. To accomplish this, and at the same time to keep the tube dust-tight, the nicol is enclosed in one side of a double chambered box. The other side is left vacant and the box may be slid to and fro according as ordinary or polarized light is desired. A metal sheath protects this box from above.

The microscope as here described in a case with a single eye-piece, but without objectives, may be obtained for $108.00. With two eye-pieces (one with cross-hairs and the other with micrometer) and two objectives ($\frac{3}{4}$ and $\frac{1}{5}$ inch) its cost is $135.00. The cost of a solid brass stand is about $25.00 more.

The instrument as here figured is less expensive than the importation of the lower grades of European petrographical stands; and considerable practical experience with it has shown that it renders decidedly better service.

Petrographical Laboratory, Johns Hopkins University, November, 1887.

ART. X.—*A new Ammonite which throws additional light upon the geological position of the Alpine Rhætic;* by WILLIAM B. CLARK.

IN a paper* upon the geology of a part of the northern Tyrol, published in Munich in February, 1887, I described among several new forms a species of ammonite of the genus *Arcestes*, which is of some considerable importance, as pointing to the probable position of the Rhætic beds.

In the region above mentioned this much debated formation consists of the three typical divisions of *Haupt Dolomit*, *Kössener Schichten* and *Dachstein Kalk*, the lower or Haupt Dolomit being plainly subdivided into a zone of dolomite of somewhat over 1,000 feet in thickness, overlaid by a thinner zone of limestone, the so-called Platten Kalk of Gümbel. The lower zone is probably unfossiliferous, with the exception of some interstratified beds of asphalt which contain ganoid scales; while the upper, although containing numerous ill-defined gasteropods, doubtless of the genus *Rissoa*, affords no distinctive forms that would of themselves demand a close union either with the underlying Trias or overlying Jura. The Kössener Schichten, in contradistinction to the lower division, are very fossiliferous and present the chief ground of discussion. The rock is a dark limestone, often of a marly, schistose character, with frequent interstratified beds of marl, that grades down insensibly into the Platten Kalk. The fossils show numerous affinities both with Triassic and Jurassic forms, but for the most part appear to be of the former character. They are largely corals, brachiopods and lamellibranchs, and the example here cited is the first case of a well-defined ammonite. The genus *Choristoceras*, so commonly encountered, is a degenerate form placed with the *Ceratitidæ*, and has small value in this connection. The third division, the Dachstein Kalk, is of white limestone, and contains almost exclusively lithodendron-like corals, though the large *Megalodon triqueter*, the characteristic bivalve of this zone, is frequently encountered. It is without doubt of coral-reef origin, as many physical facts along its contact with the Lias give proof.

Facts seem to indicate that these different divisions, certainly so far as the Kössener Schichten and Dachstein Kalk are concerned, are only facies, and may under suitable conditions be interchangeable.

* Ueber die geologischen Verhältnisse der Gegend nordwestlich von Aachensee mit besonderer Berücksichtigung der Bivalven und Gasteropoden des unteren Lias. 8°. 45s., 2 taf., 1 Karte. München, 1887. (Inaugural Dissertation).

When we examine the stratigraphical relation of these beds to the underlying Trias we find that no unconformity exists, but that an insensible gradation often takes place from one to the other; while toward the Lias, on the other hand, although unconformity does not exist, yet the break is so marked and clearly defined that we are unprepared to admit an intimate connection between the Rhætic and Lias.

Stratigraphical and paleontological evidence in the Eastern Alps is, then, strongly indicative of a close affinity of the Rhætic to Trias; and the Arcestes species, which we will now describe more in detail, adds another important proof to this more or less generally accepted fact.

ARCESTES RHAETICUS, n. sp.*

The ammonite in question, to which, from its important occurrence, I have given the name of *Arcestes rhæticus*, has the following dimensions:

Diameter	70^{mm}
Height of last whorl	40
Thickness	50
Umbilicus	14

The shell is involute, with rounded dorsal surface, and the cast shows upon the last whorl two depressions, which run in a straight line over the convex back, and which were occasioned by successive contractions or interior thickenings of earlier mouth-edges. The sutures form regularly decreasing series of lobes and saddles from the dorsal siphuncle toward the interior. These lobes and saddles are finely branched, the latter containing upon the outside 4–5, upon the inside 3 obliquely diverging divisions. Beyond the dorsal and the two lateral saddles there are only two auxiliary saddles present. The dorsal lobe is divided by a median saddle into two points, which are very considerably deeper than the lateral lobes. The latter are by means of small branches two- or three-pointed.

This species belongs to the group of the *Galeati*, and shows close affinities to *Arcestes giganto-galeatus* Mojs., from the Hallstädter Kalk.

We have thus a form which belongs to a family and genus most characteristic for the Trias and until now never found above that formation. The Lias has not a single representative. The interest in this particular species is greatly heightened from the very close similarity in outward form and minute division of the lobes to *Arcestes giganto-galeatus*. This fact, if we were to consider the Rhætic beds as belonging to the Lias, would be without a parallel, for on account of the ex-

* Figured in the paper before mentioned, Plate I, fig. 3, *a*, *b*, *c*.

treme variability of the ammonites, the most marked changes are shown from stratum to stratum. Hence it is scarcely possible that a well-marked form could be preserved through any considerable extent of time or any marked change in the conditions of life. In other classes of animals many cases can be cited where forms have continued unchanged for long periods of time, but when such is observed among the ammonites it is certainly a proof of the faunal affinity of the formations considered and a strong reason for uniting them most closely in the geological system.

Before closing this brief contribution it will not perhaps be irrelevant to refer in a word to the general positions held by geologists of different countries upon this question, as shown in their reports to the Committee for the Unity of Nomenclature at the Geological Congress at Berlin. In this report the opinion of French and English geologists was decidedly in favor of according a closer relationship of the Rhætic beds to Lias than to Trias, while the weight of evidence obtained from German sources plainly pointed to the opposite conclusion. The inability and folly of endeavoring to correlate the strata of widely separated regions is thus most forcibly shown, since facts which in certain localities warrant the close association of conformable beds, in others preclude the union of apparently synchronous horizons.

Geological Laboratory, Johns Hopkins University, Oct. 1887.

Art. XI.—*Three Formations of the Middle Atlantic Slope;* by W. J. McGee. With Plate II.

Introduction.

The Middle Atlantic Slope may be described as that portion of Eastern United States which sheds its waters directly into the Atlantic Ocean and in which the principal rivers rise within the Appalachian mountain system. Thus defined, it extends from near the Mohawk and Hudson on the north to the Roanoke (called the Staunton in the middle part of its course) on the south, or from southern New York to northern North Carolina. Its principal rivers, in addition to those mentioned, are the Delaware, the Susquehanna (including its continuation, Chesapeake Bay), the Potomac, and the James; and its smaller but yet notable streams extending to tide water are the Raritan, the Schuylkill, the Brandywine, the Patapsco, the Patuxent, the Occoquan, the Mattaponi, the North Anna and South Anna (which unite to form the Pamunkey), the Appomattox, the Nottoway, and the Meherrin.

By geologic structure, by topographic configuration, by behavior of streams, and by the various cultural conditions resulting from these natural conditions, the Middle Atlantic Slope is separable into three distinct zones:—viz, the Appalachian zone, the Piedmont region, and the Coastal plain.

In the Appalachian zone the rocks are Paleozoic, and are characteristically corrugated by greatly elongated flexures; the predominant topographic characteristic of the region is long, parallel ridges separated by flat-bottomed valleys, the whole —save the sharpest ridges—diversified by a plexus of narrow stream-cut valleys and intervening minor hills; the great rivers wander meanderingly through the mountain ranges while the smaller streams and secondaries generally gather in elongated basins bounded by the ranges, and both large and small streams flow rapidly over the rocky bottoms of narrow, steep-sided ravines or gorges; and the civil boundaries and the routes of travel and traffic are generally determined by the parallel ridges and greater waterways, while the industries are determined largely by the resources of the rocks—anthracite and other coals, iron, building-stone, etc.,—the thin-soiled mountain slopes being unsuited for agriculture and allied pursuits.

The Piedmont region comprises an area of highly inclined crystalline rocks, abundantly diked, veined and faulted; its surface is a rather strongly undulating plain without conspicuous eminences, inclined seaward, and everywhere graven deeply by the larger and to proportionately less depths by the smaller waterways, which thus give origin to endless mazes of minor hills; its hydrography comprises the great rivers which meander irregularly through it, and a widely-branching dendritic system of secondary and tertiary drainage in which the individual members have no uniformity in direction, in which the basins are irregularly rounded or pyriform, and in which the divides are low and inconspicuous and constantly curving and recurving in labyrinthine convolutions; while, as in the Appalachian region, both the larger and smaller streams are unnavigable and rush rapidly over the rocky bottoms of sharply cut valleys, the declivity of the streams culminating at the seaward side of the zone, where all, river and rivulet alike, descend to tide level in cataracts and rapids. The civil boundaries of the region follow the waterways and transect the divides, the lines of traffic are either confined to the greater valleys or distributed over the surface, and the pursuits of the people are largely determined by the soil and its products.

In the southern part of the area, the Appalachian and Piedmont zones are sharply separated by the Blue Ridge—the easternmost member of the parallel Appalachian series; but in

Pennsylvania this mountain ridge looses its integrity and continuity and the boundary between the two zones is indefinite, while in northern New Jersey and southern New York the natural boundary fails and only an arbitrary demarkation can be drawn between the zones so sharply distinguished in Virginia and Maryland.

The Coastal plain extends from the line of cataracts and crystalline rocks to the ocean. Structurally, it consists of generally incoherent deposits of later Mesozoic and Cenozoic age, slightly inclined seaward but otherwise undisturbed; topographically, it is a plain, trenched by broad but shallow tidal estuaries and thus separable into smaller plains which sometimes undulate gently but irregularly, and again take the form of steeply-scarped terraces miles in extent, cut by steep-sided ravines and deeply scalloped along the greater waterways; the hydrography comprises the broad flat-bottomed estuaries into which the principal rivers are transformed on entering the plain, and local drainage systems of widely branching dendritic type in which the principals are also generally estuarine toward their mouths; the divides are but labyrinthine and crenulated remnants of an imperfectly drained plain only partially invaded by erosion; and throughout the region the water is slack except toward the heads of the adolescent drainage ways. The political boundaries and principal lines of traffic are determined by the great water avenues, while the civil boundaries and lesser lines of traffic are independent of the physiography, and the industries grow out of the products alike of sea and soil and out of the natural facilities for traffic and transportation.

The common boundary of the Piedmont region and the Coastal plain is one of the most strongly marked physiographic and cultural lines on the land surface of the globe: On the one hand there is a great series of crystalline rocks giving origin to a characteristic soil in which all streams, from the greatest rivers to the smallest brooks, flow through constricted gorges in a succession of cataracts or rapids; while on the other hand there is a series of incoherent and undisturbed deposits of clay, sand, and gravel through which the waters, gathering in the more elevated zones, move sluggishly in broad tidal estuaries. The boundary has long been known among students of manufacturing industries as the *fall-line;* yet it is even more noteworthy as a line of deflection in the rivers than as one of declivity. The great waterways of the Middle Atlantic Slope maintain their courses through Appalachian ranges and Piedmont highlands alike; but on reaching the low-lying Coastal plain they are turned aside, literally by a sand-bank little higher than their depth, and thence hug the hard

rock margin for scores of miles before finally finding their way into the open ocean. By this deflection of the rivers the northern half of the Coastal plain is nearly insulated; the isthmuses between the Raritan and the Delaware, between Claybank creek and Elk river, between the Patapsco and the Anacostia, and between Potomac creek and the Rappahannock, from tide-water to tide-water, are low, and but 20, 15, 25, and 5 miles in width respectively; measured directly along the fall-line, so that, the Hudson is barred from the Rappahannock by only about 60 miles of land and unnavigable water. The deflected portions of the rivers indeed occupy a great trough skirting and accentuating the Piedmont escarpment.* This remarkable physiography has materially affected the culture of the region: The pioneer settlers of the country ascended the tidal canals to the falls of the rivers where they found, sometimes within a mile, clear fresh water, the game of the hills and woodlands and the fish and fowl of the estuaries, and, as the population increased, abundant water-power and excellent mill sites, easy ferriage and practicable bridge sites; here the pioneer settlements and towns were located; and across the necks of the inter-estuarine peninsulas the pioneer routes of travel were extended from settlement to settlement until the entire Atlantic Slope was traversed by a grand social and commercial artery stretching from New England to the Gulf States. As the population grew and spread, the settlements, villages, and towns along this line of Nature's selection waxed, and many of them yet retain their early prestige—for Trenton, Philadelphia, Wilmington, Baltimore, Washington, Fredericksburg, Richmond, and Petersburg are among the survivors of the pioneer settlements; and the early stage route has become a great railway and telegraph line connecting North and South as they were connected of old in a more primitive fashion. The influence of natural conditions upon man and his institutions is nowhere else more strikingly exemplified.

No discussion of the phenomena of the Atlantic slope is intelligible without clear comprehension of the great physiographic divisions into which it is naturally separated. These divisions are represented graphically in the accompanying stereogram, which also exhibits the essential continuity of the Coastal plain to the great submarine escarpment off the Atlantic coast; the submarine profiles being based on soundings by the Coast Survey, the Fish Commission, etc., while the indicated sub-marine structure is hypothetic.

* It is shown elsewhere (7th Annual Report, U. S. Geol. Survey) that this trough is due to a post-Tertiary displacement along which movement is now in progress, probably at a rate as high as in the well-known recent faults of the Wasatch or the Sierras.

Four years ago the writer undertook to ascertain the origin and relations of certain conspicuous deposits in the District of Columbia, under the direction and auspices of the U. S. Geological Survey. It was soon found that while certain formations of the region—especially those containing fossils,—had received more or less study, while the various formations had been classified by means of the fossils contained in a few of them, and while the entire region had even been repeatedly mapped geologically, nothing was accurately known of the exact relations of the different fossiliferous and unfossiliferous deposits forming the portion of the Coastal Plain within and contiguous to the District of Columbia; it was soon found, moreover, that the formations in question are not only generally unfossiliferous in the district, but that the deposits themselves are destitute of constant and definite petrographic and structural characters whereby the stratigraphy might be ascertained; and thus it was early found difficult, if not impossible, either to correlate the different local exposures and deposits among themselves, or to establish their relations to formations already classified elsewhere by commonly employed methods. Accordingly, the investigation was commenced *de novo;* and in default of fossils or definite structural characters, locally applicable methods, standards, and criteria were developed as the work progressed: Conditions of deposition were inferred from deposits, and continent-movement was in turn inferred from evident conditions of deposition superinduced thereby; conditions of degradation in unsubmerged areas were inferred from the topographic forms thereby developed, and, since degradation is preëminently dependent on base-level, another means of inferring continent-movement was thus evolved; the record of events interpreted from earth-forms fashioned in accordance with determinate principles on the one hand was compared with the record interpreted from correlative deposits on the other hand, and history was thus deduced from independent but consistent and cumulative testimony; and final correlations were made through deposits regarded not only as rocks but also as indices of continent movement, and at the same time through the correlative topographic forms. In short, the methods, standards, and criteria have been of necessity physiographic rather than paleontologic or petrographic.

Certain preliminary results of the work appear of sufficient moment to merit a place in the standard medium of American students of science. They are summarized in the following pages.

In the present sensitive if not revolutionary condition of geologic terminology, it may be wise to define, without spe-

cially defending, the term "formation" as employed in this article. It is applied to a naturally defined series of deposits, evidently formed by a definite set of agencies within a determinate area during a definitely limited period—an easily recognizable structural, chronologic, and taxonomic unit.

The formations described are: (1) the *Potomac*, consisting of irregularly bedded and heterogeneous sand, clay, arkose, gravel, etc., of Mesozoic age and forming the base of the series of unaltered deposits of the Coastal plain, named from the river on which it is best developed; (2) the *Appomattox*, a series of predominently orange-colored sands and clays of later Tertiary age, also named from the river on which it is typically exposed; and (3) the *Columbia*, a series of delta and associated littoral deposits formed during a brief period of submergence in early Quaternary time, named from the district in which it is typically developed and in which it is first systematically studied. Certain deposits of each of the formations have already been investigated by different geologists, but they have not hitherto been correlated and systematically combined. The Potomac formation has already found place in geologic literature and taxonomy; the Columbia has been defined and briefly described in print;* but the Appomattox is here defined and named for the first time.

Professor William M. Fontaine began his elaborate investigations of the later Mesozoic formation and its flora in Virginia some time before the study of the contemporaneous deposits of the District of Columbia was taken up by the writer; but a meeting was soon arranged, notes were compared and exchanged, and a detailed examination of the principal exposures in Virginia, in the District, and in Maryland south of Baltimore, in which Mr. Lester F. Ward participated, was undertaken in the summer of 1885; during this joint study the characters of the Potomac formation were worked out and its name (previously proposed by the writer) adopted, the Appomattox formation was discriminated, and many features of the Columbia formation were brought to light; and it is a pleasure not only to acknowledge indebtedness to these gentlemen, and especially the former, for the greater share of our knowledge of the Potomac and Appomattox formations, but to record their substantial concurrence in the following statements and inferences concerning them. It is an equal pleasure to add that the phenomena of the Columbia formation have been more or less carefully examined in the vicinity of Washington by the same gentlemen and several other geolo-

* Rep. Health Officer of the District of Columbia, 1884–85 (1886), 20; this Journal, III, xxxi, 1886, 473; Proc. A. A. A. S., xxxvi, 1888, 221; etc.

gists, that acknowledgments are due to them for pertinent and valuable suggestions, and that all coincide in the essential conclusions as to its genesis and age set forth in subsequent pages.

The Potomac Formation.

Character and Distribution.—The southernmost observed occurrence of the formation is at Weldon, N. C., where a bed of obscurely stratified arkose, interspersed with well rounded quartzite pebbles, appears in the north bank of the Roanoke beneath the railway bridge. The deposit rests on an unequally eroded surface of gneiss, is not over a foot thick, and is unfossiliferous; but its composition and structure are characteristic, and there is little doubt as to its identity.

Better exposures occur on the Nottoway river just below Bolling's bridge. An irregularly and obscurely stratified arkose, unquestionably belonging to this formation, here rises four or five feet above low water, and is unconformably overlain by three or four feet of stratified greenish-blue clay containing Eocene fossils; and exposures of similar character occasionally occur in the river channel within the next five miles up stream. In all of these outcrops the deposit exhibits a typical and easily recognizable aspect: it is a nearly homogeneous, granular, loosely aggregated, almost mealy mass of quartz grains (generally angular but sometimes rounded), flakes and grains of kaolin (sometimes so little decomposed as to retain the form of the parent crystals of feldspar), and scales of mica, with an unimportant admixture of loamy particles, and now and then a rounded or irregular pellet of white plastic clay. The fresh surface is commonly light gray in color, but is frequently flecked with white and stained with brown in curiously curved lines. In structure it is either massive or obscurely stratified and cross-laminated; but even where the bedding is most distinct it is rarely consistent and continuous for more than a few feet vertically or a few yards horizontally. Except for its obscure structure planes, its pellets and lenticular pockets of clay, and the slight admixture of loamy matter, the mass could hardly be distinguished from decomposed granite or gneiss *in situ*. Some of these deposits on the Nottoway river were observed and referred to the "secondary class of rocks" by W. B. Rogers in 1839;* but *a propos* to the interesting question of geographic changes during the historic period, it is significant that Rogers failed to find the formation where it is now best exposed but found it "nearly on a level with the water" at a point "about 4 miles above Bolling's bridge" where it now rises fully 8 feet above the river; the

* Geology of the Virginias, 1884, 261.

indications being that the river has here deepened its channel several feet since 1839.

The next exposures of the formation occur on the Appomattox between Petersburg and its mouth at City Point; the most conspicuous being Point of Rocks (some four miles above the mouth) where the larger part of the material is an arkose similar to that on Nottoway river, interspersed with well rounded quartz and quartzite pebbles and rounded or irregular masses of plastic clay, interstratified with laminated clay beds, and the whole so firmly lithified that the solid quartzite pebbles fracture as readily as the matrix. The deposit here forms a prominent bluff 50 or 60 feet high, the material of which has been largely quarried as a building stone.

On James river the formation is notably exposed between Richmond and Deep Bottom, a few miles above the mouth of the Appomattox. Perhaps the most abundant constituent is arkose, such as occurs on the Nottoway, generally friable but sometimes lithified; but the arkose beds are frequently intercalated with beds of massive or laminated clay and heterogeneous sand or gravel, sometimes forming the greater part of the mass. Where laminated, and especially in the lenticular bands intercalated between beds of arkose, the clay frequently contains well preserved impressions of leaves; and silicified wood is common in the sandy and gravelly portions, as are lignitized trunks and branches of trees in the beds of clay. One of the most conspicuous elements in the deposits exposed on James river is its large pebbles and bowlders, reaching three or four feet in diameter, sometimes of Piedmont gneiss (which crops out in the river channel within a few miles of Dutch Gap), but more frequently of quartzite sometimes containing *Scolithus* borings and casts of brachiopods identifying it with the axial quartzites of the Blue Ridge. It is noteworthy that W. B. Rogers recognized the materials of this formation in borings from an artesian well at Fort Monroe at a depth of 835–907 feet.*

Interesting exposures of the formation occur on the South Anna river (where, as at Point of Rocks, it is in part a firmly lithified arkose containing well rounded pebbles of quartz and flakes and pellets of plastic clay) as well as on the Little river, the North Anna, the Mat, the Taponi and its tributaries, on Massaponax creek, and indeed in nearly every considerable valley or deep ravine, and occasionally on the surface, between the South Anna and the Rappahannock. It is generally overlain by the orange sands and clays of the Appomattox formation; and in the neighborhood of Hanover Junction it reposes unconformably upon the petrographically similar, but disturbed

* Ibid., 733–5.

and diked, Rhætic beds. Here too, the quartzite pebbles, so abundant on the James and Appomattox, disappear.

About Fredericksburg the formation is well exposed and exhibits some noteworthy characters: it consists predominantly of locally lithified arkose with abundant pebbles either irregularly disseminated or arranged in bands and beds, and numerous bowlders of gneiss and vein-quartz (quartzite being altogether absent) up to two feet or more in diameter, together with heterogeneous sand containing a considerable element of finely divided diffused clay; while lenticular beds of clay are frequently intercalated in both arkose and sand, and in some exposures constitute the major part of the mass. As on the James, the clay is massive, obscurely bedded, or finely laminated, and sometimes contains abundant leaf impressions; and here, as elsewhere, silicified and lignitized wood are common in the sand and clay respectively.

Thus, south of the Rappahannock the formation consists of an indivisible mass of arkose, sand, clay and gravel, generally overlapped by the Tertiaries, and exposed only along waterways and over a limited area between the two Anna rivers.

North of the Rappahannock the formation increases in volume and in diversity, and forms the surface over a zone several miles in width between the Eocene margin and the Piedmont crystallines. Near the mouth of Acquia creek it has an observed thickness of 180 feet, mainly of lithified arkose (long known as a fairly valuable building stone and extensively used in old structures in Washington, Alexandria, and Fredericksburg), intercalated with plant-bearing clay beds. Midway between Fredericksburg and Acquia creek the characteristic phases of the formation as developed in the south are found to be overlain by a bed of clay of obscure or inconstant structure, containing occasional intercalations of arkose or beds of pebbles; and this clay deposit, which lies beneath the Eocene and is generally unfossiliferous, increases in thickness northward. At the same time, isolated patches of gravel identical with that of the body of the formation, and evidently outliers insulated by erosion, begin to appear along the marginal portion of the Piedmont zone, generally capping eminences of circumdenudation. These outliers are sometimes 25 or 30 miles within the fall-line.

Between Acquia creek and Washington the formation continues to form the surface over a considerable zone; its lower part maintains the characters exhibited farther southward, as shown by excellent outcrops at many points on the Potomac river, and in ravines and railway cuttings to the westward; and the superjacent clays progressively increase in thickness without material change in character. On Occoquan river quartzite

pebbles, which are absent southward nearly to the James, again appear, and at Pohick creek become an important element in the formation; while the leaf impressions so abundant to the southward disappear.

About Washington the formation comprises two members sometimes discriminated with difficulty but apparently unconformable, the lower consisting of friable arkose or more heterogeneous sandstone, with lenticular partings and intercalated beds of clay and notable accumulations of quarzite pebbles (which in the westernmost outcrops become respectable bowlders), and the upper consisting of irregularly and discontinuously bedded clays, with occasional intercalated beds of sand and pebbles. The clays comprising the greater part of the upper member, like those intercalated within the lower, are of obscure or inconstant structure, variable in composition, and diverse in color: they are sometimes massive and again finely laminated, now silty and unctuous, again made up of flakes and pellets of kaolin, and elsewhere intermingled with sand and grit; they are commonly gray, whitish, or lead-colored, but again pure white, blue, black, pink, red, brown, purple, or mottled with part or all these colors, generally in soft and delicate tints. Silicified and lignitized wood and even lignitized stumps *in situ* occur in both members; but identifiable plant remains are not here found Both members are locally stained and cemented by ferruginous infiltrations. Isolated outliers, made up principally of well-rounded quartzite and vein-quartz pebbles up to six or eight inches in diameter, crown eminences on both sides of the Potomac river, some of those on the south occurring fully twenty miles west of the continuous formation boundary. In this latitude the formation generally constitutes the surface over a belt fully fifteen miles in with, from the Piedmont gneiss on the west to the overlapping Eocene beds on the east; but the eastern boundary cannot be accurately drawn by reason of the puzzling graduation into newer deposits, sometimes filling ravines and sometimes covering considerable areas, made up of redeposited Potomac materials. Attention was called to the deposits of the formation at Washington by W. B. Rogers in 1875.*

Between Washington and Baltimore the upper division of the formation (the "Iron Ore Clays" of Tyson†) forms the surface generally and is extensively exposed in the cuttings on both railways and in the numerous workings from which disseminated nodules of carbonate of iron are extracted, and has recently yielded abundant dinosaurian remains; and at Balti-

* Proc. Bost. Soc. Nat. Hist., vol. xviii, 1875.

† 1st Rep. State Agricultural Chemist of Md., 1860, 30, 42.

more, as well as on the Patuxent and Patapsco rivers and their tributaries, the lower division is exposed and occasionally yields plant remains closely allied to those found in Virginia.

Both members of the formation appear in the precipitous shores of the head of Chesapeake bay, the sandstone only on the north, but the white, blue, purple and varigated clays on both east and west; and along Sassafras river these clays are unconformably overlain by the pyritous clays and greensands of the Maryland Cretaceous. Identifiable fossils have not been found in the sandstone member at this locality; but a few plant remains were found in the clays. The magnificent exposures of both the Potomac and Columbia formations here are described in detail and fully illustrated elsewhere.*

Extensive outliers of gravel occur on both sides of the Susquehanna several miles from the body of the formation, notably at Webster on the south and Woodlawn (or Battle Swamp) on the north of the river.

In extreme northeastern Maryland and in northern Delaware the sandstone member of the formation is not exposed as a continuous body, though it is represented by occasional isolated outliers of gravel upon the marginal Piedmont hills; but the superjacent clays appear in a number of localities, and form the subterrane over a considerable zone parallel with the Piedmont escarpment. They have been studied by Chester, who designates them "Plastic Clays," and refers them to the "Lower Cretaceous (Wealdon?)."†

So between the Rappahannock and the Brandywine the formation is a continuous terrane, consisting of a series of clays reposing perhaps unconformably upon a series of sands and gravels, while outliers of the inferior division crown the crests of the Piedmont plateau many miles from the main body; but northward it contracts and is again represented only by isolated remnants and exposures.

In southeastern Pennsylvania both members of the formation have been recognized by different geologists and have been variously classed. Clays apparently representing the upper member occur in the northeastern part of Philadelphia county where they have been referred to the Wealden;‡ the gravelly outliers representing the lower member in the vicinity of Philadelphia have been designated the "Bryn Mawr Gravel" (from a locality of typical outcrop) and referred to the Tertiary by Lewis;§ and similar exposures in Delaware county have been

* "Notes on the Geology of the Head of the Chesapeake Bay," 7th Ann. Rep. U. S. Geol. Survey (in press).

† Proc. Acad. Nat. Sci., 1884, 250–1.

‡ 2nd Geol. Surv. Pa., Report X, Hand Atlas of Pa., J. P. Lesley, 1885, Plate 46.

§ Proc. Acad. Nat. Sci. Phil., xxxii, 180, 269, 272; Ibid. 296, *et seq.*; Journ. Franklin Inst., xcv, 1803, 371–73; and elsewhere.

mapped by C. E. Hall, who designated the deposit "Ferruginous Conglomerate," and followed Lewis in referring it to the Tertiary.* The low-lying clays in the valley of the Delaware are not well exposed, have yielded no fossils, are not known to be connected with the plastic clays of Delaware, and cannot be certainly correlated with the upper member of the formation; but the gravelly outliers belong to a series traced from the Rappahannock river northward, everywhere sustaining identical relations to the underlying rocks and to the topography, and everywhere petrographically similar to a characteristic phase of the formation as typically developed in Maryland and Virginia, and may be confidently correlated with the lower member. Indeed, in the exposure in Media the most abundant materials are characteristic kaolinic arkose and more heterogeneous brown ferruginous sands such as occur about the head of Chesapeake bay, coarse gravel being but a subordinate element.† In the vicinity of the Susquehanna the gravel of the outliers is generally coarse and abundant; over the plateau between that river and the Schuylkill it is finer and less abundant: and toward the latter stream it again grows coarse and the outliers become more conspicuous.

North of the Schuylkill the lower member is typically developed at several localities in Rose valley, in the northwestern part of the village of the same name. The deposit is an obscurely bedded arkose, generally friable but sometimes lithified, containing well worn quartz and quartzite pebbles both disseminated irregularly and in lines, together with pellets and flakes of clay, the whole similar to the deposits found in Virginia; and silicified wood occurs in small quantities, but neither leaf-impressions nor the bands of clay in which they are commonly preserved were found. The mass is irregularly stratified and evidently undisturbed, and rests directly upon tilted Triassic sandstone. Again, three or four miles north of Conshohocken, extensive deposits of white, pink, and mottled plastic clay, petrographically indistinguishable from the upper member of the formation where typically developed, are found overlying gravelly arkose. The clay beds are largely worked for pottery, while the subjacent arkose is excavated and screened for building sand and road metal—indeed there is a considerable area north of Conshohocken and Norristown in which the proximity of the Potomac is proved by the presence of its materials in roadways and foot-paths, and in the mortar of houses and barns. Still farther northward outliers of gravel generally finer than that found in the vicinity of the Schuylkill occur,

* 2nd Geol. Surv. Pa., Report C5, 1885, 10–13, and map.

† C. E. Hall notes pebbles 6 inches in diameter at this point; but so large pebbles are probably rare, and were not found by the writer.

as in the neighborhood of Broad Axe, near Three Tuns, three miles northeast of Hatboro, and indeed generally on the subordinate divides and eminences northwest of Chestnut Hill and Edge Hill. The gravel in these outliers is fine (seldom over an inch in diameter), well rounded, generally of quartzite, and commonly imbedded in a scant matrix of arkose. A compact pinkish quartzite is abundant and gives distinction to the gravel.

The substantial continuity of the formation as represented by outliers is here broken, no exposures being known between the east-flowing tributaries of Neshamin creek (near Churchville) and the Delaware river, a distance of nearly twenty miles; but two miles above Trenton on the New Jersey side of the Delaware there is a distinctive deposit locally known as the "Yellow Rocks," made up of arkose, sometimes lithified but generally friable, containing abundant well rounded (but frequently disintegrated) quartzite pebbles, disseminated, arranged in lines, or accumulated in pockets, together with pellets and flakes of white plastic clay. The deposit is irregularly stratified and inclines northwestward, but at a considerably less angle than the immediately subjacent Triassic strata. No fossils were found in the beds, but they are petrographically similar to those everywhere characteristic of the lower division of the Potomac formation, totally unlike those of the Triassic sandstones in structure, composition, and attitude, equally unlike the Raritan clays found in the vicinity, and quite distinct from the gravels and loams of the Columbia formation by which they are overlain; and on the whole it seems evident that the deposit represents the sandstone member of the Potomac formation. Somewhat similar and probably contemporaneous deposits of stratified sand occur two miles below Trenton beneath the Raritan clays.

Midway between Princeton and New Brunswick, N. J., an anomalous and hitherto unclassified deposit of friable ferruginous sandstone crowns the southernmost of the Triassic trap ridges, and is locally known as the "Sand Hills."* It consists of massive or irregularly stratified and sometimes cross laminated brown sands, occasionally cemented by ferruginous infiltration, with a few intercalated lines of white or pinkish plastic clay, and is strikingly similar to the non-kaolinic sands of the Media outlier and of the body of the formation as exposed north of the head of Chesapeake Bay. This outlier is completely isolated and unfossiliferous; but it is distinct from the Triassic sandstone on both sides of the ridge in all diagnostic features, and is, moreover, manifestly newer than the trap dike, which was itself formed after the sandstone was de-

*Geology of N. J., 1868, 227, 342.

posited. At the same time it is too unlike the well-defined Cretaceous and Tertiary formations found a few miles to the southeast to warrant correlation with, and is therefore evidently older than, any of these formations. In short, it appears to be a remnant of a formation largely removed by erosion before the later Cretaceous submergence, just as are the Potomac outliers in Virginia and Maryland; and on this indirect evidence of its chronology together with that of its petrography it may be provisionally referred to the lower member of the Potomac, although nearly twenty miles from its nearest supposed, and thirty-five miles from its nearest known, homologue.

It should be noted that the Raritan clays, which are perhaps equivalent to the superior member of the Potomac, and almost certainly newer than the sands and gravels of the two exposures just mentioned, are tentatively regarded as Jurassic by Whitfield.*

Briefly, the Potomac formation consists of two perhaps unconformable members, of which the upper is an inconstantly bedded and protean clay of variegated colors, either clean or sandy and pebbly, and the lower a generally friable sandstone, arkose, or gravel of irregular and inconstant structure. The upper member extends from the Rappahannock at least to the Delaware and probably to the mouth of the Hudson, either forming or closely approaching the surface over a somewhat sinuous zone 275 miles long and only ten miles or less in maximum width, overlooked throughout by the Piedmont escarpment. As a continuous terrane the lower member forms a still narrower zone flanking the Piedmont escarpment from the Appomattox to beyond the Susquehanna, and reappears in isolated exposures southward to the Roanoke and northward to beyond Delaware, over a total length of 300 miles; while as a series of insulated remnants crowning the hills of circumdenudation toward the coastward margin of the Piedmont region it occurs occasionally from near the James certainly to the Delaware and probably to the Raritan, over a zone from five to forty miles in width. The tenuity of these zones of outcrop is but an accident of degradation and deposition. Studies about the head of Chesapeake Bay led to the conclusion that the former westward extension of the formation can be reliably inferred from the topographic configuration of the Piedmont region, the western part of which has a drainage evidently determined by lateral heterogeneity of the vertically-bedded terrane and a characteristic topography resulting therefrom, while the eastern

* Brachiopoda and Lamellibrachiata of the Raritan Clays and Greensand Marls of N. J., Monog. U. S. Geol. Surv., ix, 1885 (Mem. Geol. Surv. N. J., 1885), 23.

part has a drainage independent of the varying obduracy of the terrane and therefore evidently superimposed by a formation (which could only have been the Potomac) now generally removed by erosion; this conclusion has since been verified by the discovery of isolated remnants of the Potomac formation on many parts of the area of supposed superimposed drainage; and it may be confidently inferred from the configuration of the Piedmont plain that about half of its area north of the James River (but not much more than half) was submerged beneath the Potomac sea and at one time covered by its deposits. A great extension of the formation eastward may also be inferred from the Fort Monroe boring, fifty miles from the nearest outcrops, in which undoubted Potomac deposits were found in considerable volume. The thickness of the formation, either original or present, has not been accurately ascertained; the upper member must approach 350 feet and the lower 250 feet near Baltimore and Acquia creek respectively, from which points both attenuate gradually, giving an aggregate (the maxima being nearly 100 miles apart) of perhaps 500 feet; and while the loss by erosion at the localities of maximum thickness has not been great, it cannot be readily evaluated.

Stratigraphic Relations.—South of the James river, the Potomac deposits rest upon an irregularly eroded and sometimes deeply ravined surface of highly inclined crystalline rocks, the inequality in altitude of the base within a mile on the same meridian (the formation and its subsurface having a considerable eastward inclination) reaching 100 feet or more. On that river the formation rests upon the irregular surface of the Richmond granite at the "fall-line," and upon the truncated edges of highly tilted gneisses and schists down the river for 20 or 30 miles; while to the westward outlying gravel patches repose unconformably on the tilted and faulted Rhætic* beds forming the Richmond coal field. Near Hanover Junction, the upturned Piedmont crystallines and the faulted, tilted, and diked strata of the Rhætic are alike overlain by the Potomac arkose which fills deep ravines in, and conceals irregularities of, the subjacent surface; and thence northward to the river from which they take their name, the Potomac sandstones repose unconformably upon irregularly eroded surfaces of gneiss, except at Drainesville (25 miles west of Washington), where a gravelly outlier rests on the planed edges of tilted Triassic sandstones. At Washington the inequality in altitude of the base of the formation, which evidently filled the valley of the Mesozoic progenitor of the Po-

* Fontaine, "Older Mesozoic Flora of Virginia," Monog. U. S. Geol. Surv., VI. 1883, 2, 96, 128.

tomac river, is fully 200 feet within a mile and a half. North of the Potomac river, the deposits, both in the main body and in the outliers, generally repose upon the eroded surface of the Piedmont crystallines, the depth of local ravining reaching some 250 feet about the mouth of the Susquehanna and proportionately less depths on the smaller streams; but the great outlier north of the Schuylkill in Pennsylvania, which exhibits all of the characteristics of the main body of the formation, rests in part upon crystallines, in part upon folded Silurian limestones, shales, and quartzites, and in part upon degraded Triassic sandstones and shales. On the Delaware the "Yellow Rocks," believed to represent the formation, rest upon a planed surface of tilted Triassic sandstone and highly inclined gneiss; and the still more doubtfully identified outlier forming the "Sand Hills" near the Raritan, rests upon an apparently eroded Triassic trap dike. In short, the formation everywhere reposes on a deeply degraded surface of upturned Piedmont crystallines, folded Silurian strata, tilted, faulted, and diked Triassic sandstones, and diked and displaced Rhætic beds; and it is significant that this surface is a generally uniform plain, inclined seaward and deeply incised by great waterways, coinciding closely with those of the present.

South of the Rappahannock the Potomac formation is overlain by the Appomattox formation, the fossiliferous Miocene, and the Eocene; between the Rappahannock and the Patapsco it is overlain by the Eocene; north of the Patapsco it is overlain so far as known by the upper Cretaceous; and in the absence of these, and up to certain altitudes indicated later, it is overlain by the Columbia formation; the relation generally, but not invariably, being one of visible unconformity. The unconformity between the Columbia and the Potomac is well exhibited in representative sections at Fredericksburg, Washington, Baltimore, and the head of Chesapeake bay, but over the interfluvial plains and on certain slopes about Washington the formations, though widely diverse in age, intergraduate so imperceptibly that it is impossible to demark them; there is notable unconformity between the Appomattox and Potomac formations on the Roanoke and in some sections on the Appomattox and James rivers, but in other sections on the last named rivers (at Fredericksburg and elsewhere), there are deposits of composite character certainly belonging to one or both of these formations which cannot be discriminated even in the same section; the Miocene rests on the Potomac in the local absence of the Eocene at Petersburg and Richmond, but no noteworthy unconformities have been observed; the Eocene is unconformable to the Potomac on the Nottoway and generally about Richmond, and notably in a railway cutting near Brooke

(where two deep ravines in the Potomac are filled with fossiliferous Eocene deposits), though in some sections at Richmond the two cannot be discriminated, and at Good Hope Hill, near Washington, Eocene fossils occur in deposits made up of Potomac materials supposed to be *in situ* before the discovery of the fossils; and on Sassafras river there is a marked unconformity between the pyritous clays and greensands of the upper Cretaceous and the subjacent Potomac clays, while in the best section about the head of Chesapeake bay (Maulden's Mountain) the sequence from massive Cretaceous greensand above to iron-bearing Potomac clay below is unbroken save by arbitrary lines. In short, it is evident that the Potomac terrane has ever lain near sea-level, and has alternately suffered less by denudation and accretion by sedimentation during oft-repeated oscillations, has been deeply ravined during one epoch only to have the ravines filled largely with its own materials but with some foreign matter and more recent fossils during the next, and has contributed material to each newer formation of the Coastal plain. Its characteristic pebbles have indeed been successively transferred to the newer Mesozoic beds, to several of the Cenozoics, and finally incorporated in the Quaternary.

There is an apparent unconformity between the two members of the Potomac, marked by beds and pockets of gravel superimposed upon erosion planes, as in a noteworthy section three miles southeast of Washington; but since local unconformities, including both erosion planes and accumulations of gravel and bowlders, occur at various horizons in each member, there is some doubt as to the importance of this apparent unconformity.

Fossils.—Until recently animal remains were believed to be exceedingly rare in the formation: fragments of a rib of a cetacean and part of the teeth and bones of a reptile supposed to be related to the Iguanodon are recorded by Tyson from the upper member in Maryland,* the latter being the *Astrodon Johnstonii* of Leidy;† six undescribed species of the fresh water genera *Unio* and *Anodonta* and several "ctenoid fish scales" associated with "leaves of dicotyledonous trees" are noted from the upper member in western New Jersey, and identical *Unios* "from the banks of the Potomac" by Cope;‡ Conrad described from the plastic clays of New Jersey (which are either equivalent to or newer than the upper division of the Potomac formation, but which he regarded as Triassic), two lamellibranchiates, *Astarte veta*, and *A. annosa*;§ and

* First Report Maryland Agricultural Chemist, 1860, 42; cf. Uhler, Johns Hopkins University Circulars, vol. ii, No. 21, 1883, 53.

† Cretaceous Reptiles of the U. S., Smithsonian Contributions to Knowledge, vol. xiv, 1865, 102.

‡ Proc. Acad. Nat. Sci., xx. 1868, 157. § Am. Jour. Conch., iv, 1868, 279.

Whitfield has more recently recognized from the same clays (which he, too, is disposed to refer to the Triassic) five lamellibranchiates—*Astarte veta*, *Ambonicardia Cookii*, *Corbicula emacerata*, *Corbicula annosa* (Conrad's *Astarte annosa*), and *Gnathodon tenuides*.* In the course of an examination of the formation extending over some years, Fontaine has found but a single animal fossil, viz: the posterior portion of a homocercal fish about the size of a salmon from the lower member on James river. Careful search during the past three months has led to the discovery of moderately abundant dinosaurian remains of upper Jurassic type and the upper member between Washington and Baltimore, some of which have already been described by Marsh.†

At several points on the Appomattox and James rivers, on both Anna rivers, about Fredericksburg, on Acquia creek, at Baltimore, and at a number of other localities the laminated beds of clay intercalated within the lower member yield abundant and well preserved leaf impressions; and throughout the whole extent of the formation both members abound in silicified and lignitized wood. Fontaine has collected and investigated the plant remains, and has just sent to press a monograph containing descriptions of over 370 species, of which more than 300 are new. Extensive collections of silicified and lignitized wood have also been made from both members and have been investigated by Knowlton; and eight new species belonging to two new genera have been discriminated and are described and illustrated in a memoir now in press.‡

Viewed as a whole, the Potomac flora is unique. It is, moreover, of special interest in that it records a stage in the development of plant life not known to be represented elsewhere on the globe. The plant history of the earth falls naturally into two eons, instead of the three represented by animal life, during the first of which the various non-dicotyledonous forms (the cryptogams, cycads, conifers, and monocotyledons) of archaic type prevailed, while throughout the second dicotyledonous forms of modern type have greatly predominated,—the transition from the archaic to the modern type being sudden, and the bipartite division being consequently stronger and more trenchant than the tripartite division based chiefly on animal remains. Now the exact period of transition from the archaic flora to the modern one (hitherto placed about the middle of the Cretaceous)§ appears to be represented in the Potomac flora; there is a commingling of primitive and recent types in nearly every plant bearing clay bed; the types

* Monog. U. S. Geol. Surv., vol. ix, 1886, 23–27.
† This Journal, xxxv, 1888, 89–94.
‡ Bulletin U. S. Geol. Surv. (in press).
§ Ward, 5th Ann. Rep. U. S. Geol. Survey, 1885, Plate lvi.

are about equally represented in the entire section; and the transition is recorded not only in the commingling of types but in a measure by the assumption of modern external forms while the plants yet retained the archaic internal structure.

It is significant that well preserved leaf impressions are not found in the formation about Washington, in the lower member at the head of Chesapeake bay, in the deposits near the Schuylkill, in the "Yellow Rocks" at Trenton, nor in the immediate vicinity of Richmond—the plant-bearing localities on the James being several miles from the fall-line,—i. e., about the mouths of the Mesozoic prototypes of the great rivers of the region.

Taxonomy.—The general facies of the wonderfully rich flora most closely approaches that of the middle and lower Neocomian of Greenland and Europe, and Fontaine is disposed to refer the formation to the lower Cretaceous on this evidence; but since the flora is manifestly too nearly unique to permit precise correlation, and since Marsh finds the vertebrate remains to be distinctly upper Jurassic, the formation must be at least provisionally assigned to the latter period.

The Tuscaloosa formation of Alabama appears to be the precise equivalent of the Potomac;* and Hill has recently collected data indicating that the Trinity formation (Dinosaur Sand)† of Texas and Arkansas is coeval with the Potomac and Tuscaloosa.‡

Sources of Materials.—Roughly classified, the materials of the Potomac formation are (1) quartzite pebbles, (2) quartz pebbles, (3) arkose, (4) quartzose sand, (5) plastic clay, and (6) various combinations of these.

1. The distribution of the quartzite pebbles is significant: They are abundant and large on James river but diminish rapidly both in abundance and size about to the Appomattox on the south and the South Anna on the north, where they finally disappear—none occurring on the Nottoway or Roanoke, nor on the North Anna, the Rappahannock, or the intermediate smaller streams. They reappear near the Occoquan, and increase rapidly in abundance and size to the Potomac, where they form a predominant element in parts of the formation; but they again diminish in size and abundance northward, becoming inconspicuous north of Baltimore, to once more increase in size and number about the Susquehanna, where the outliers consist almost exclusively of well rounded quartzite pebbles and bowlders. North of the Susquehanna like relations obtain, so far as size is concerned, the pebbles gradually diminishing in size over the Susquehanna-Schuylkill divide, enlarging

* Bulletin U. S. Geol. Survey, No. 43.

† American Naturalist, vol. xxi, 1887, 172.

‡ Science, vol. xi, 1888.

again about the Schuylkill, once more decreasing in size in the outliers lodged behind Chestnut hill and Edge hill, and again assuming considerable dimensions on the Delaware; but in this part of the area of the formation the quartzite pebbles occur on the smaller streams and over the divides as well as on the great rivers. Finally, in the Sand Hills quartzite is nearly or entirely absent. In short, the quartzite pebbles occur only in the vicinity of those rivers which flow through the quartzites of the Appalachian and upper Piedmont regions, and their abundance and size vary with the dimensions of the rivers and the proximity of the ridges.

The composition of the pebbles is equally significant: Those found about Washington and Richmond sometimes exhibit *Scolithus* borings and casts of brachiopods, etc., identical with those found *in situ* in the axial quartzites of the Blue Ridge and adjacent Appalachian ranges in their less metamorphosed portions; the pink quartzite of the pebbles found over the Schuylkill-Delaware divide is in all respects similar to that of certain exceptionally obdurate ledges in the quartzitic axes of the low ranges here encroaching upon the Piedmont region; and the distinctive pebbles are in both these as well as in other cases confined either to the vicinity of the distinctive ledges or to the lower reaches of the rivers transecting them.

So by distribution and composition, the quartzite pebbles of the Potomac formation may be traced to their parent ledges in the Appalachians; and their distribution indicates at the same time the ancient river-courses and the shore lines along which they were transported.

2. The quartz of the second class of pebbles (which sometimes assume the dimensions of respectable bowlders) is petrographically identical with the vein quartz everywhere intersecting the Piedmont crystallines; the pebbles, like those of quartzite, are generally largest in the greater valleys and toward the western margin of the formation, though considerable bowlders occasionally occur in all parts of it; they are most abundant where the quartz veins are large and numerous; and local peculiarities in the vein quartz are reflected in the leeward pebbles. It is evident, in short, that the pebbles are derived from adjacent veins. Indeed in a section in the northwestern part of Washington a train of fragments of a quartz vein intersecting the Archean gneiss and projecting into the superjacent Potomac gravels, is traceable in the gravels for some distance before the fragments so far lose their angles as to become undistinguishable from the neighboring erratic pebbles.

3. The arkose is made up of angular grains of quartz, crystals of feldspar or flakes of kaolin, scales of mica, etc., the

whole sometimes so similar to disintegrated granite or gneiss as to be distinguished only with difficulty. It reaches its best development toward the base of the formation, and especially in the smaller valleys and ravines or on the subjacent gneissic surface; and it is not found in perfection along the lines of the larger rivers. Its petrography and distribution alike justify the inference that it is granitic debris, not far transported.

4. By far the larger part of the quartzose sand, whether in homogeneous beds or intermingled with other constituents of the formation, consists of rounded quartz grains of doubtful origin, but evidently worn by transportation; a smaller part consists of angular quartz grains and flakes such as might be produced by impact of masses during transportation; a yet smaller part is made up of rudely crystalline grains such as result from the disintegration of vein quartz; and the least important element in volume, though it is locally conspicuous and significant, consists of more or less perfect crystals of quartz such as might form the residue of disintegrated granite after the solution and removal of the less obdurate constituents. All of these sources are doubtless represented in the sands of the Potomac.

5. The clay occurs in minute flakes (sometimes of crystalline form) in the arkose, in rounded and irregular pellets and balls up to an inch or more in diameter in the arkose and sand beds, in lenticular or sometimes continuous bands intercalated with sand, and again in considerable beds exhibiting more or less definite structure planes; but whenever pure it is clean, plastic, kaolin-like, and evidently derived from a common source, and the smaller flakes retain the shapes of feldspar crystals undistinguishable from those of the adjacent Piedmont gneisses. The clay in the larger masses it is true appears to be thoroughly triturated, and was evidently deposited in finely divided condition; and the pellets and balls appear to have been washed from such beds and redeposited in conjunction with other materials; but the structural differences between the pseudo-crystalline and the water-laid phases of the clay are no greater than would inevitably result from the trituration and assortment accompanying the breaking up of gneiss or arkose and the separation of the materials of unlike specific gravity and solubility.

6. The heterogeneous and ever varying accumulations of composite character which constitute the larger part of the formation are, qualitatively, just such as would be formed by the assortment and deposition of the different materials by powerful currents; but the quantity of coarse materials in the Potomac formation is greater than would result from simple admixture of the disintegrated gneiss of the Piedmont zone and such

proportion of Blue Ridge quartzite, vein quartz, etc., as appear to be mingled with it, suggesting that the portions of the formation now exposed were littoral, and that the finer materials were swept into deeper off-shore waters.

The History recorded in the Formation.—The conditions of deposition of the lower member of the Potomac formation may be inferred from its structure and composition: the coarseness of the predominant materials is proof of the prevalence of powerful currents or violent waves; the local accumulations of arkose and of finely laminated clay are indicative of quiescent periods, of slack-water eddies, or of sheltered spots on a stormy coast; the frequent alternation of coarse and fine deposits, the broken up and re-deposited clay beds, and the local unconformities, all suggest repeated alternations of slack water and strong currents throughout the area of deposition; the distribution of the quartzite pebbles proves that this material was brought down from the easternmost Appalachian mountains by rivers coincident with the great rivers of to-day, and the unequal altitude of the base of the formation along the rivers and the prevalent coarseness and inconstant structure of the deposits there indicate that the ancient rivers embouched into deep turbulent estuaries, while the interosculation of some of the estuarine deltas and the coarseness of the deposit connecting others prove violent wave action along the intermediate shore; the dearth of remains of marine and estuarine animals is suggestive of turbulent waters; and the peculiar distribution and preservation of the plant remains suggests encroachment of the Potomac ocean upon lands covered with a luxuriant flora. The conditions of deposition of the upper member appear to have been similar but quieter.

From the relations of the formation to the foundation upon which it rests, from structure and composition and indirectly from the conditions of deposition indicated thereby, the physiographic conditions attending the deposition of the Potomac formation may be inferred: The surface upon which the deposits rest is formed of dislocated strata of Archean, Cambrian, Silurian, Triassic and Rhætic age, all degraded to a plain as uniform as the Piedmont zone of to-day—a plain destitute of noteworthy eminences despite the great heterogeneity of the rocks, and one which accordingly must have been reduced to base level; yet the unequal altitude of the deposits about the waterways indicate that this plain was ravined as deeply as is the present Piedmont plain; and the slight sinuosity of the shore line, despite the depth of the ravines, is proof of pronounced seaward inclination of the surface.

Thus the structure, composition, and stratigraphic relations of

the Potomac formation, when freely interpreted, give the outlines of an intelligible and harmonious picture of the Atlantic slope during and for some time antecedent to the Potomac period: Before the initiation of Potomac deposition, but subsequent to the accumulation of the Triassic and Rhætic deposits and to the displacement and diking by which they are affected, there was an eon of degradation during which a grand mountain system was obliterated and its base reduced to a plain which, as its topography tells us, was slightly inclined seaward and little elevated above tide—the Piedmont zone alike of the later Mesozoic and the present; and over this plain meandered the prototypes of the Delaware, the Susquehanna, the Potomac, the James, and the Roanoke, within a few miles at most of their present courses and but a few hundred feet above their present channels, flowing slack and in shallow valleys because at base level. There followed a slight elevation of the land, when the rivers attacked their beds and excavated valleys as deep as those to-day intersecting the Piedmont plain; but whether or not there was concomitant tilting of the land, the phenomena thus far fail to indicate. Then came the movement by which the deposition of the Potomac formation was initiated—the deeply ravined base level plain was at the same time submerged and tilted oceanward; its waterways became deep but short estuaries; deep oceanic waters extended quite to the intermediate shores; the declivity and transporting power of the rivers was increased; and the accumulation of coarse delta and littoral deposits progressed rapidly. With continued deposition the sea gradually shoaled, the declivity of the land decreased, the materials became finer and finer; there was probably temporary emergence of the land about the middle of the Potomac period, followed by renewed submergence without seaward tilting during which the clays of the upper member were laid down; and the period was finally closed by an emergence represented by the unconformity between the upper Potomac and the glauconitic deposits of the Maryland Cretaceous.

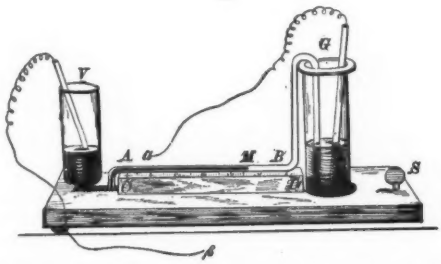
There is a great hiatus in the geologic history of the Atlantic slope: The history is fairly legible up to the termination of the Paleozoic deposition, and it is even more clearly legible from mid-Cretaceous time to the present; but the hiatus includes the most interesting period in the evolution of the eastern portion of the continent. The transfer of sea and land: the elevation and corrugation of the Appalachians, and the profound displacement and metamorphism of the Piedmont rocks; the degradation of thousands of feet if not miles of strata and the transportation of the materials whither no man

knows; the deposition of the Triassic and Rhætic rocks under conditions which no geologist has ever clearly pictured in imagination—at least to the satisfaction of his fellow geologists; the Triassic displacements and diking; the post-Triassic degradation of thousands of feet of strata and the removal of the debris to other regions—these and many other remarkable episodes have been completely blotted out of the geologic record as commonly interpreted. But the Potomac formation narrows the hiatus: the formation itself carries the record back from mid-Cretaceous time to the earliest dawn of the Cretaceous or the closing episodes of the Jurassic; and the post-Rhætic and pre-Potomac degradation will tell the story of the Jurassic as eloquently, when men have come to read geologic history in erosion as well as in deposition, as if the deposits of the period were exposed to observation instead of lying beneath the thousands of feet of newer strata forming the Atlantic bottom. So while the hiatus is not yet closed it is reduced by a fifth, a fourth, or perhaps a third of its length.

Art. XII.—*Experiments with the Capillary Electrometer of Lippmann;** by Julius Howard Pratt, Jr.

The objects of this investigation have been, first, to determine the limits within which the given form of electrometer can be used; secondly, to ascertain whether the polarization of the mercury surface is such as to prevent the passage of a current while the instrument is in use; and, thirdly, to determine the amount of charge retained at the polarization surfaces when the mercury column is in equilibrium.

1.



The instrument used in these experiments was constructed as follows: V is a thistle tube, the tubing of which (A B) was bent in the manner indicated (fig. 1); G is a small glass vessel

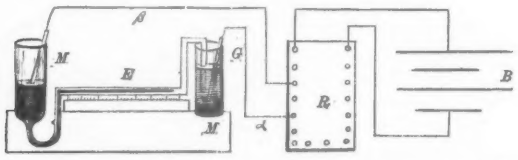
* Abstract of a thesis presented for the degree of Doctor of Philosophy at Yale University, June, 1887.

containing mercury and dilute sulphuric acid; α and β are platinum wires which serve as conductors for the electric current. They pass through the glass tubes in vessels G and V, and are fused into the tubes at the end; the platinum electrodes, accordingly, have only a small area. The end of A B itself is filled with sulphuric acid to M, the mercury meniscus. S is a leveling screw. The whole is mounted on a wooden base to give it stability. C D is a millimeter scale on which the readings are made.

For most of the work done the unaided eye, or a small magnifying glass was sufficient to make the readings,—as the differences of deflection for slight differences in E. M. F. were comparatively great. For instance, the difference of deflection between ·02 Daniell and ·03 Daniell was, for a given adjustment, 2·4 millimeters; hence, ·1^{mm} (which can easily be read) showed a difference of about ·0004 Daniell. For the experiments in quantity of electricity a micrometer was used, by which readings could easily be made to $\frac{1}{200}^{mm}$ with accuracy.

I. Lippmann states * that the value of the capillary constant in his instrument increases for increasing potentials to about ·9 Dan. and then diminishes. The same results are obtained with the form here given.

2.



Two Daniell's cells are connected as shown in figure 2. R is a resistance-box of 10,000 ohms, through which the current passes. By the wires α and β, fractions of the current are made to pass through the electrometer. The accompanying table and plot (No. I, fig. 4) will exhibit the results. Column I gives the fraction of the E. M. F. of a Daniell cell which produces the deflections given in column II.

TABLE I.—March 1, 1887.

E. M. F.	Deflect.	E. M. F.	Deflect.	E. M. F.	Deflect.	E. M. F.	Deflect.
·008 Dan.	1^{mm}	·16 Dan.	28·2^{mm}	·60 Dan.	77·4^{mm}	1·2 Dan.	80^{mm}
·016	2·3	·20	34·7	·80	88·0	1·4	64
·04	7·2	·30	49·5	·892	90·3	1·6	50·2
·08	14·5	·40	60·7	1·0	89·0	1·8	42·5

In taking the deflections for the higher of these potentials 1·2 to 1·8, electrolytic action was noticed and bubbles of gas

* Annales de Chim. et de Phys., Ser. V, vol. v; E. Mascart, Traité d' Électricité Stat., ii, p. 550.

formed on the mercury surface. It is necessary in all these investigations that the current pass in such a way as to produce hydrogen polarization. Oxygen polarization does not change the capillary constant in any regular manner. Moreover the use of even comparatively low potentials with oxygen polarization causes chemical action so that the surface of the mercury is fouled, which seriously interferes with the action of the instrument. Two series of deflections of the meniscus for given electro-motive forces were made. In one series hydrogen polarization was used, and in the other, oxygen. The series with hydrogen polarization, was regular, as before; but that of oxygen, except for very low potentials, was so irregular that no conclusions could be drawn. Apparently the position of the meniscus depended largely on the chemical action caused by the current.

In using Lippmann's electrometer it might be convenient to dispense with the mercury contact and employ only sulphuric acid and platinum. A set of observations was accordingly taken, in which the mercury was removed from the vessel G and the platinum wire served as electrode. The surface of the platinum in contact with the sulphuric acid being so small, it was found that, owing to polarization of the platinum-sulphuric acid surface, a given potential would produce a deflection only a fraction of that produced with mercury as electrode. With the platinum electrode the maximum point on the curve was for potential about 1·5 Dan. instead of 0·9 Dan. as was the case with the mercury electrode. The small capacity of the platinum electrode will sufficiently account for this. If, then, platinum electrodes be used in place of mercury, care should be taken to have their capacity great compared with the capacity of the mercury meniscus.

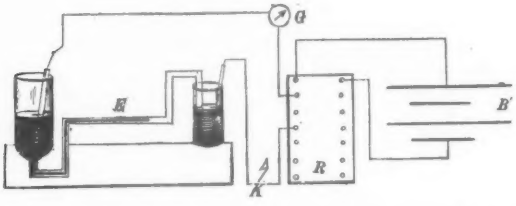
It should be noted, then, that, in actual use, Lippmann's electrometer makes a good means of measuring low potentials, up to 0·6 or 0·7 Dan.; that care must be taken to avoid oxygen polarization and employ hydrogen polarization only; that the inner surface of the glass tube should be kept free from dust and traces of acid, which occasion irregularities in the deflection of the mercury. The instrument in this form can be used to advantage for comparing E. M. F. of different batteries. Only a part (a known fraction) of the current should be used; as, otherwise, the limits of the instrument might be exceeded. By using a micrometer for reading deflections, about $\frac{1}{20000}$ Daniell's cell E. M. F. can be detected. The electrometer might be used successfully in many cases for a galvanometer, especially where it is desirable not to alter the main current by a derived galvanometer circuit. It may be recommended for

such service, first on account of its comparative rapidity in coming to a state of equilibrium; secondly, because it is practically a dead-beat instrument; and, thirdly, because the readings may be made directly, and show immediately their relation to E. M. F. The ease with which the instrument is constructed puts it within reach of all who have some ability in glass-blowing.

II. *To ascertain whether a current passes when the mercury surface is polarized.*

For this purpose the instrument was connected as before, and, in addition, a reflecting galvanometer and a key were placed in the branch with the electrometer. The deflections were observed by means of a telescope and millimeter scale about four feet from the galvanometer. It was easy to detect a deflection amounting to $0{\cdot}1^{mm}$ which, for the distance of the galvanometer from the scale meant an exceedingly minute deflection; and hence an insignificant current. The arrangement can be seen from figure 3. B is the battery of two Daniell's cells. R is a resistance-box of 10,000 ohms. E is the electrometer; K, the key; and G, the galvanometer.

3.



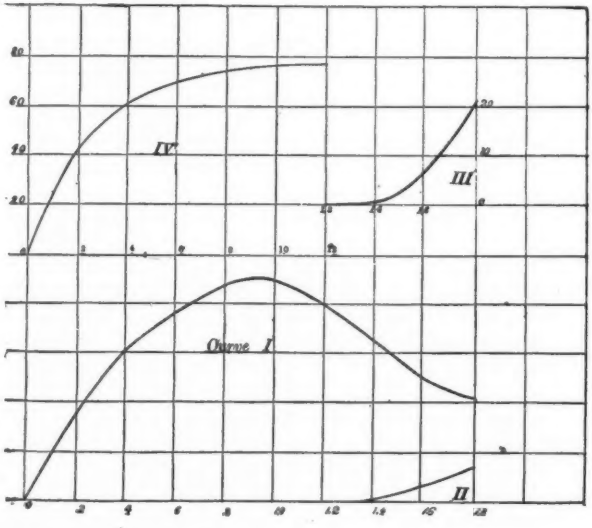
The current from the battery was passed through the resistance-box. Known fractions of this current made the circuit through the electrometer and galvanometer. Before the mercury reached the position of equilibrium, there was evidence of a current through the galvanometer; but when once the mercury came to rest, the deflections of the galvanometer ceased. This was true for low potentials and until the E. M. F. reached about 1·4 Dan. Plot II. and Table II., given below, will show the results obtained for hydrogen polarization. The first column gives the potential of the current passed through the galvanometer, and the second gives the final deflection of the galvanometer needle, measured in scale divisions (^{mm}) and indicating the strength of the current through the galvanometer.

TABLE II.—March 22, 1887.

E. M. F.	Deflect.	E. M. F.	Deflect.	E. M. F.	Deflect.
·01 Dan.	0	·40 Dan.	0	1·41 Dan.	1·0mm
·02	·1mm	·60	·1mm	1·42	2·0mm
·04	0	·80	0	1·50	3·0mm
·08	0	·90	0	1·60	7·0mm
·10	·2	1·00	0	1·80	13·0mm
·20	0	1·40	·5mm		

The deflections obtained for the E. M. F. 0·02 D., and 0·1 D. 0·6 D. are evidently accidental. Neglecting these, it is evident that no appreciable current passes through the electrometer until the potential of its surface reaches 1·4 Daniell. This, it will be remembered, is not the highest point of the curve showing the deflection of the mercury in the electrometer. That point is reached when the potential of the mercury surface is 0·9 Daniell. The point at which conduction begins is about the point at which electrolysis begins. The collection of gas bubbles (before mentioned), when potentials of something over one volt were used, indicate that electrolysis actually does take place. The results of this investigation will prove that conduction through the electrometer begins about the same time.

4.



On April 1, 1887, a series of measurements was taken to determine the exact point at which conduction begins. In this series, before each observation, the sulphuric acid was run

through the tube to cleanse the surface; and the bubbles of gas, if any, were driven from the tube. The arrangement of the instrument was the same as before, and the readings were taken with great care.

TABLE III.—April 1, 1887.

E. M. F.	Deflect.	E. M. F.	Deflect.	E. M. F.	Deflect.
1·20 Dan.	0	1·32 Dan.	·25 mm	1·44 Dan.	1·30 mm
1·21	0	1·34	·35	1·50	2·30
1·22	·05 mm	1·36	·45	1·60	6·70
1·24	·10	1·38	·55	1·70	12·90
1·26	·15	1·40	·60	1·80	21·20
1·30	·20	1·42	1·20		

Since in a Daniell's cell the replacement of one gram-equivalent of zinc evolves 24,200 cal. of heat; and, when one gram of hydrogen and 8 grams of oxygen unite to form one gram-equivalent of water, 32,462 cal. of heat are evolved,* therefore a cell of potential $\frac{32462}{24200}$ Dan. (equals 1·34 Dan.) would be just sufficient to decompose water. For about this potential (1·34 Dan.) it might be supposed that conduction through the electrometer would take place. Molecular changes which accompany electrolytic action may, very probably, slightly precede it and cause variations in the electrical conditions which allow a current to pass. If, moreover, there were any leakage in the instrument, this would be evidenced by a current through the galvanometer, when the potential was below 1·34 Dan. Defective insulation would cause leakage, and conduction would begin at a somewhat lower potential. It will be seen by reference to the table that conduction begins not far below the electrolytic limit, i.e., at 1·22 Daniell; and that, at first slowly and then rapidly, it increases with the potential.

When the mercury was treated with oxygen polarization, conduction began at very low potentials. An E. M. F. of 0·01 D. gives a permanent deflection of 6^{mm}; and other higher potentials gave higher deflections; which, however, seem to follow no uniform law. This, like the former experiments with oxygen polarization, shows that such polarization cannot be too carefully avoided.

III. *To determine the capacity of the electrometer.*—Three methods of making this determination were tried. The nature of the instrument makes it impossible to secure rigorously accurate results. However, several not inconsistent values of the instrument's capacity were secured, and the final determinations should be regarded as fair approximations. By the first method a condenser of one microfarad capacity was charged with electricity at a known potential (V), and the charge was

* Daniell's Physics, p. 609. London, 1885.

then passed through the electrometer and the deflection noted. By reference to the E. M. F. curve for the electrometer the potential (V′) for the given deflection was found. The electricity being divided between the two instruments the proportion will hold $V : V' :: C+C' : C$, where V equals the potential of the condenser, V′ equals the potential of the electrometer, and C and C′ the capacities of each. By division, $V-V' : V' :: C' : C$, or $C'=\frac{V-V'}{V'}C$. As V′ is found to be small compared with V, the equation $C'=\frac{V}{V'}C$ will be approximately true. This method has some disadvantages which make it impracticable for accurate results. The discharge from the condenser being practically instantaneous, its full force is exerted at once on the mercury, the inertia of which is apt to carry it beyond the position to which an equal amount of electricity, in the ordinary use of the instrument, would bring it.

On the other hand, the tendency of the electrometer to discharge itself acts in the opposite direction and prevents the exact determination of the deflection. The results from this method cannot be accepted as satisfactory. The only safe conclusion is that the capacity of the electrometer is great compared with that of the condenser.

By the second method employed, the condenser and electrometer were placed in the same circuit, and the current passed through both in series. The ratio of the E. M. F. of the current to the potential indicated by the deflection of the electrometer gives the capacity of the electrometer compared with that of the condenser. The self-discharge of the instrument acted very disadvantageously. When the current, passing through the electrometer, had charged the condenser, the latter acted like an infinite resistance in the circuit, and the mercury of the electrometer, instead of remaining at the point to which it had been deflected, moved from it and gradually returned to zero. As the readings were made with a micrometer, and could not be taken immediately, this movement prevented accuracy. The indication was, as in the other method, of a capacity far greater than that of the condenser.

To secure more satisfactory results a third method, without condenser was resorted to. A resistance box of 250,000 ohms, of which 240,000 ohms were used, was put in circuit with the electrometer, and currents of known potentials were passed through the two. As the passage of a definite amount of electricity through the electrometer is necessary to bring the meniscus to a given position, the movement of the mercury was retarded by the introduction of the large resistance. The slow motion made it possible at any instant to determine the position of the

meniscus. The deflections for equal successive intervals of time were thus obtained. Series were made for various E. M. F. from 0·2 D. to 1·0 D. with accordant results. The table and curve IV (fig. 4) will show the results when a current of 0·6 Dan. was used. With a large resistance in the circuit, the mercury never reaches the point to which a current of the same potential with small resistance would bring it. The deflections of 0·6 Dan. without large resistance is 81^{mm}. That found after thirty minutes passage of the current with resistance was 78^{mm}.

TABLE IV.—May, 1887.

Deflect.	Time.	Deflect.	Time.	Deflect.	Time.	Deflect.	Time.
24·8^{mm}	1 min.	66·2^{mm}	5 min.	75·2^{mm}	9 min.	76·8^{mm}	13 min.
43·0	2	69·8	6	76·2	10		
54·0	3	72·2	7	76·5	11		
61·0	4	74·0	8	76·8	12		

Since the movement of the mercury is slow we may assume that, during the excursion of the mercury, the E. M. F. at the surface of polarization varies according to the curve of the potentials, and that at any instant the position of the meniscus determines the E. M. F. We have, thus, a means of computing the capacity of the instrument for a given potential. By Ohm's law $I=\frac{E}{R}$. Also C (capacity) $=\frac{Et}{R}$. By reference to curve IV, it will be seen that a portion of the curve between any two points taken sufficiently near to each other will differ but slightly from a straight line; hence the mean of the E. M. Forces at the beginning and end of any short interval of time will give the mean potential of that interval. If E_1 equals E. M. F. at the beginning of the first interval of time; E_2 that at the beginning of the second, etc., the capacity is represented by the equation

$$C=\frac{t}{R}\left(\frac{E_1+E_n}{2}+E_2+E_3+\ldots\ldots\ldots+E_{n-1}\right)$$

R is the inserted resistance plus the resistance of the electrometer. The latter was found to be, approximately, 10,000 ohms; so that R equals 250,000 ohms. The interval of time (t) was 60 seconds Computation gives for potential 0·2 Dan., C equals 314 mfds.; 0·4 Dan., C equals 445 mfds.; 0·6 D., C equals 605 mfds.; 0·7 D., C equals 648 mfds.; 1·0 D., C equals 730 mfds. The values for the capacity are approximate and will apply only to the instrument in question. In this the radius equals 0·64^{mm} about, and hence the surface of the mercury, regarded as hemispherical equals about 2·572 sq. mm. The radius of the tube was found by measuring the length of a column of mercury (for the hemispherical shape of whose ends due allowance was made) in the tube, and weighing the mercury. From these two factors the radius of the tube was computed.

In regard, then, to the Lippmann's Electrometer it has been shown: First, that, when hydrogen polarization is used, the deflections of the meniscus may be taken as proportional to the E. M. F. for very low potentials, and that for potentials up to 0·9 D. an empirical curve will show the relation between the E. M. F. and the deflection. Secondly, that polarization is complete, and that no appreciable current passes through the electrometer until it be charged to a potential near that at which electrolytic action begins. Thirdly, that the capacity of the Lippmann Electrometer is very considerable, compared, for example, with that of the Thomson Quadrant Electrometer, being in the particular instrument studied, several hundred microfarads.

The investigation, of which a summary is given in the preceding pages, was carried on at the Sloane Physical Laboratory of Yale University under the direction of Prof. A. W. Wright, to whom I would here express my grateful acknowledgment for his encouragement and advice.

Cornell University, Ithaca, N. Y., November, 1887.

ART. XIII.—*On the Period of the Rotation of the Sun as determined by the Spectroscope;* by HENRY CREW, Assistant in Physics, Johns Hopkins University.

ZÖLLNER* and Vogel were the first to measure the rotation of the sun by the use of Doppler's principle. For this purpose, they employed the so-called "reversion spectroscope" of the former. This had two prisms with their refracting edges turned in opposite directions, thus forming two spectra, side by side, in opposite directions, the one serving as a vernier for the other; any displacement of a line will be doubled, since the deviation in one spectrum is the opposite of that in the other. For their results, however, the authors claim little more than a qualitative value.

Hastings,† two years later, by a very ingenious device compared the spectra of the center and the limb of the sun, but gave no *quantitative* observations on the displacement of the lines which he observed in passing from one of these regions to the other. Langley‡ has devised an instrument which gives, in juxtaposition, the spectra of light from any two points, distant 180° on the circumference of the solar disc. He has noted, in rather an incidental way, the displacement due to rotation of

* Zöllner: Pogg. Ann., cxiv, 449, 1871.
† Hastings: this Journal, v, 369, 1873.
‡ Langley: this Journal, xiv, 140, 1877.

the sun, when examining an *equatorial* diameter, and the absence of any displacement when comparing the extremities of the *polar* diameter, and has also commented on this as a means of separating the solar and telluric lines.

In 1876, Prof. Young* published the first accurate measurements of the linear velocity of a point on the solar surface. These were made with a spectroscope attached to a 9½ inch equatorial, and fitted with a Rutherfurd grating, ruled with 8640 lines to the inch. His result is for a mean latitude of 7° and is reduced to the equator by Faye's formula for the proper motion of sun spots. The velocity thus obtained, 1·42 miles per second, is so large as to suggest a physical significance, viz: that the reversing layer, whatever and wherever it may be, has a greater angular velocity than that layer of the solar surface in which the sun spots lie, a conclusion very interesting considering that the observations of De la Rue,† Stewart, and Loewy at Kew appeared to show a lagging behind of that layer of the solar atmosphere in which the faculæ occur, a layer probably at no inconsiderable distance *above* the altitude of sun spots.

Carrington,‡ by a magnificent series of laborious observations, extending over seven years, has determined what may be called the proper motion of the photosphere, or more strictly, the law according to which sun spots move relatively to one another in latitude and longitude.

Have the different parts of the *reversing layer* a relative motion, and if so, what is the law which governs it?

It was in the hope of obtaining at least a partial answer to this question that the following observations were made.

Apparatus.—The light was furnished by an equatorial heliostat with an auxiliary plane glass mirror. Leaving the heliostat, the ray next fell upon a condensing lens of 8^{cm} diameter and 135^{cm} focal length, thus giving upon the slit of the collimator, an image $12{\cdot}5^{mm}$ in diameter. For the following apparatus to move the image across the slit, I have to thank the kindness and skill of Prof. Rowland. The condensing lens was screwed into a rectangular wooden frame which was fastened at the bottom by a single bolt to a larger iron frame. This bolt was parallel to the optical axis of the lens, and the lens could be made to rotate about it through an arc of 5 or 10 degrees, the arc being limited by adjustable stops. The iron frame was, in addition, capable of lateral motion, while the lens in the wooden frame could also be adjusted vertically. These adjustments enabled the observer to bring either limb of the

* Young: this Journal, xii, 321, 1876. † Proc Roy. Soc., xiv, 37.
‡ Carrington: Observations on solar spots, London, 1863.

sun exactly on the slit, and to compensate for any slight error in placing the heliostat or in the rate of its clock. The levers by which these motions were accomplished were placed convenient to the observer at the eye-piece. The collimator and telescope each had an achromatic objective of $6\frac{1}{2}$ inches diameter, made by Prof. Hastings; the former had a focal length of 7 feet and 3 inches, the latter of 7 feet and 10 inches. The angle made by their optical axes was 12°. Both were firmly attached to a long heavy cast iron frame. For the purpose of holding and rotating the grating, this iron frame carried upon it the tripod, circle (14 inches in diameter), and platform of a spectrometer. This whole system rested on a solid brick pier supported on heavy beams. These beams rested upon two partition walls of the new physical laboratory, making altogether a rigid, convenient, and accurate instrument, in which the relative position of the collimator, telescope, and grating, could be maintained perfectly constant.

The eyepiece of the telescope was fitted with a micrometer screw by Grunow; in its focal plane was fixed a very thin vertical glass scale, ruled in half millimeters. By this means the width of the narrow band of the spectrum during any one reading was measured, and a slight correction corresponding to this overlapping of the sun's image on the slit was introduced into the final value of each set of observations. The grating, a plane one ruled by Prof. Rowland, was 4 inches in length and had 14436 lines to the inch. The spectrum of the fourth order on one side gave superb definition, widely dividing b_3 and b_4 and the lower component of E. The definition in the fifth order was, of course, not so good—though better than most of the Rowland gratings ruled with this number of lines; but in this and higher orders it was found that about as much was lost by poorer definition as was gained by increase of displacement.

To determine the angle which the slit of the spectroscope makes with the projected solar axis, the following method was suggested by Prof. Rowland. Between the slit and the condensing lens was inserted a Steinheil prism mounted in a brass tube with a divided head. This tube was so placed as to have its axis in the prolongation of the optical axis of the collimating telescope, and was made so as to rotate about this axis carrying with it the prism. The prism was placed with its refracting edge perpendicular to the ray. Before the mirror of the heliostat was suspended a fine wire plumb line. The image of this plumb line was brought to focus on the slit plate by a spectacle lens temporarily placed between the prism and the condensing lens. The angle between this image and the slit could now be measured by rotating the prism; the zero position

of the prism being that in which two fine plumb lines, the one before, the other behind, the prism, were brought to coincidence. Having obtained this angle (by formula given below), we have but to add to it the parallactic angle, and the position angle of the sun, with their proper signs, to obtain the required angle, viz: the angle which the projected axis of the sun makes with the slit. This angle must finally be corrected for the inclination of the solar axis to the plane of the ecliptic; a correction never amounting to one per cent.

Theory and Observations.—Let V = velocity of light, 186328 miles per sec. (Newcomb and Michelson).

λ = wave length of ray observed (Rowland's Standards).

$v'-v''$ = relative linear velocity of the two limbs of the sun *at the equator.*

χ = heliocentric latitude of any point on the sun's limb at which the slit of the spectroscope is tangent; call this the "latitude of observation."

Δ = displacement of the line as measured on the micrometer.

c = value of one revolution of the micrometer screw in Ångstrom's units, *for the line observed.*

h = half the angle subtended at the center of the sun's image by the length of slit covered by the image.

θ = inclination of plane of solar equator to plane of eliptic.

φ = angular semi-diameter of the sun.

a = linear velocity of the earth in its orbits, expressed in miles per second.

Then, by Doppler's principle, we have

$$v'-v''=\frac{c\Delta \mathrm{V}}{\lambda \cos\chi}\cdot\frac{1}{\cos h}\cdot\frac{\sqrt{1-\sin^2\chi\cos^2\theta}}{\cos\chi\cos\theta}+a\sin\varphi$$

where the factor $1/\cos. h$ is the correction for the overlapping of the sun's image on the slit; this correction is sufficiently approximate except for very high latitudes, where a slight correction depending upon χ must be introduced. The factor involving the radical is the correction for the inclination of the solar axis to the plane of the ecliptic. The addition of the last term on the right (first suggested by Prof. Oliver) reduces the velocity from the *synodic* to the *true* period* of rotation. The correction due to the rotation of the earth is so small as to be negligible.

The following are two specimens of the individual observations; the quality of the one being above, that of the other below, the average.

* In comparing my final results with those of Young and Vogel it must be borne in mind that they have not made this reduction, and that therefore their values are for the synodic period.

July 16th, 1887.
Spectrum of 4th order; line, E_2;
Width of spectrum, 2^{mm};
Definition, good:
Half angle between plumb line and slit,
at $1^h\ 02^m = 24°\ 30'$
at $1^h\ 44^m = 37°\ 00$
Readings on micrometer were
begun at $1^h\ 29^m$
ended at $1^h\ 40^m$

Micrometer reading.		Displacement.
Eastern limb.	Western limb.	
rev.	rev.	
17·698	17·777	0·079
·710	·779	69
·719	·799	80
·692	·774	82
·718	·799	81
·716	·797	81
·701	·760	59
·692	·765	73
·673	·726	53
·675	·742	67
·682	·762	80
·661	·719	58
·656	·739	83
·665		
Mean ·6899	·7645	

rev.
$\therefore \Delta = 0·0746$

June 18th, 1887.
Spectrum of 4th order, line, E_2
Width of spectrum, $2\frac{1}{2}^{mm}$
Definition, fair;
Half angle between plumb line and slit,
at $10^h\ 39^m = 29°\ 54'$
at $11^h\ 53^m = 3°\ 36'$
Reading on micrometer were
begun at $10^h\ 59^m$
ended at $11^h\ 14^m$

Micrometer reading.		Displacement
Eastern limb.	Western limb.	
rev.	rev.	
17·147	17·231	0.084
·187	·267	·080
·208	·276	·068
·212	·284	·072
·196	·266	·070
·191	·273	·082
·212	·290	·078
·204	·293	·089
·212	·283	·071
·211	·284	·073
·212	·294	·082
·218	·296	·078
·214	·283	·069
17·2018	17·2785	

rev.
$\therefore \Delta = 0·0767$

To compute the "latitude of observation," χ, for these two sets, we have

$$\chi = g + p + q$$

where
- g = angle between projected image* of plumb line and slit, at the mean time of observation.
- p = position angle, taken from Secchi's table; *Le Soleil*, 2d Ed., p. 22.
- q = parallactic angle, tabulated for the latitude of Balti more.

Thus on July 16th, at $1^h\ 35^m$ P. M. we have

$$g = -68°·64;\ p = -4°·40;\ g = +41°·94$$

whence $\chi = 31°·10$.
and on July 18th, at $11^h\ 07^m$ A. M.

$$g = +39°·90;\ p = -5°·26;\ q = -32°·64$$

whence $\chi = 2°·00$,

* It must be noted that during the micrometer readings the prism was removed for the sake of definition and that, when the prism was in position, the *image* of the plumb line was rotated throguh twice the angle the prism was turned.

The following table includes all observations made; they are arranged in order of increasing latitudes. In the sixth column, are given the equatorial velocities, corresponding to the synodic period; these are obtained by dividing each of the *observed* velocities by the cosine of its respective latitude, given in column five, i.e., on the assumption that the sun rotates as a solid body. In column 7 will be found the differences between each value in column 6, and the mean of all the values in column 6.

TABLE I.

Date.	Mean Time of Observation.	Line Observed.	No. Settings.	Latitude of Observation.	$(v'-v'')-a \sin \phi$ (miles per sec.)	Differences.
July 16	11h 23m	"1474"	13	0°47	2·223	−·128
Feb. 28	1 29	b	6	1·05	2·177	−·174
July 18	11 07	E_2	13	2·00	2·150	−·201
July 18	11 42	D_1	13	6·35	2·297	−·054
July 12	11 11	D_2	13	6·64	2·070 ?	−·281
Mch. 8	1 06	5173·8	10	6·81	2·293	−·058
Feb. 28	1 42	b	8	6·96	2·408	+·057
July 12	11 52	"1474"	13	7·37	2·309 ?	−·042
July 18	10 54	E_1d	10	8·66	2·219	−·132
Mch. 8	12 50	D_1	9	10·35	2·327	−·024
Mch. 15	12 45	5173·8	10	10·37	2·531	+·180
Mch. 30	12 16	D_2	15	11·84	2·405	+·054
July 15	11 53	E_1d	13	11·86	2·067 ?	−·284
July 22	12 33	"1474$_2$"	13	14·47	2·371	+·020
Mch. 8	12 33	D_1	9	14·74	2·434	+·083
Feb. 28	12 25	5173·8	12	15·37	2·543	+·192
July 16	1 16	D_2	13	15 83	1·950	−·401
Mch. 15	12 25	D_1	9	16·06	2·272	−·079
Mch. 30	1 59	D_2	12	16·18	2·406	+·055
July 15	1 26	"1474"	13	18·36	1·914 ?	−·437
July 15	11 54	D_2	13	18·44	2·093.?	−·258
July 18	12 37	"1474"	13	19·58	2·228	−·123
Feb. 28	12 41	5173·8	7	20·75	2·756	+·405
July 22	1 00	D_1	13	21·89	2·083	−·268
Mch 8	12 41	5166·3	8	22·19	2·670	+·319
Mch. 26	1 55	D_1	10	23·17	2·720	+·369
Mch. 8	12 19	D_1	7	23·28	2·570	+·219
Mch. 16	11 47	5173·8	10	24·51	2·727	+·376
Mch. 8	11 53	5171·7	7	24·96	2·719	+·368
Mch. 11	11 53	D_1	6	26·34	2·514	+·163
Mch. 30	11 18	"1474"	22	27·16	2·565	+·214
Mch 11	11 35	5173·8	6	27·45	2·691	+·340
Mch. 8	11 38	5171·7	14	28·87	2·496	+·145
Mch. 16	11 28	D_1	10	29 00	2·360	+·009
July 12	1 41	E_1d	13	30·00	2·475	+·124
Apr. 8	11 24	D_1	10	30·64	2·366	+·015
July 16	1 35	E_2	13	31·10	2·427	+·076
July 18	1 33	E_1	13	33·51	2·211	−·140
Apr. 8	11 03	D_2	10	34·74	2·519	+·168
Apr. 8	10 38	D_1	10	40·73	2·681	+·330
July 14	2 52	"1474"	13	45·28	2·070	−·281

The observations in latitudes 6°·64, 7°·37, and all those of July 15th were made when the definition was marked "poor," "very poor," "sky covered with thin clouds," etc.; I have therefore marked these doubtful, but have not rejected them entirely. The values of $v'-v''$ above given are for the synodic period. The weight given to each observation is proportional to the "number of settings."

Reducing by the method of least squares, we have (since $a \sin \varphi = 0{\cdot}086$ miles per sec.) for the mean equatorial velocity,

$$v'-v''=2{\cdot}437\pm{\cdot}024 \text{ miles per sec.}$$

which corresponds to a true period of 25·88 days.

Errors.—When it is considered that the total displacement amounts to only $\frac{1}{77}$ of the distance between the D lines, it will not be surprising if the largest error is that made in setting the cross hairs on the lines. Two smaller errors may have been introduced by the unequal heating of the jaws of the slit; and by a slight vertical displacement of the sun's image when shifting from one limb to the other. But these must have been of the second order, for immediately before making an observation, the adjustment of the instrument was tested by setting on a sharp atmospheric line. Not the slightest motion could ever be detected. Since we require only the *difference* of the readings on the two limbs, and since these are taken in rapid succession, and under conditions practically identical, it will be observed that all the ordinary errors of the spectrometer, except that of setting the cross-hairs, are eliminated. Errors of this kind are, however, such as would, to a great extent, counterbalance each other in a large series of observations. On the contrary, a single setting differed from the mean of the series to which it belonged, on the average, by 11 per cent, while 41 sets of observations (of eleven settings each) still differ from their mean by as much as eight per cent. This leads one to suspect the presence of irregular horizontal currents. For the *regular* variation of angular velocity with latitude, described below, is certainly not sufficient to account for an average error of eight per cent. Currents having velocities, very moderate indeed, compared with some already observed by Prof. Young,* would more than account for all the irregularities of these observations even if they were perfect in other respects.

Results.—When beginning this work, I expected to find the angular velocity *decreasing* as the latitude of observation increased, as in Carrington's curve for the motion of sun spots, figured in Lockyer's *Chemistry of the Sun*, p. 425. On the

* See also Schellen: Spectrum Analysis, (London, 1885), pp. 378–388.

contrary, it will be seen that, taking either of the observations made during the month of March, or those made in July, there appears to be a gradual *increase* of daily angular motion with latitude. For the values of $v'-v''$, given in column 6, Table I, are equatorial values, reduced from higher latitudes of observation, on the assumption that the sun rotates as a solid body; they are therefore proportional to the angular velocities in their respective latitudes of observation. From column 7, Table I, it is seen that the differences, between each particular value of the equatorial velocity of rotation and the mean of them all are, for the lower latitudes, mostly negative; for the higher latitudes, mostly positive. If there is any physical meaning to be attached to this, it would seem that while the sun-spot layer (or photosphere, if they be the same) is *accelerated* in the neighborhood of the equator, the layer, which by its absorption gives rise to the Fraunhofer lines, tends to *lag* behind, having here a smaller angular velocity than in higher latitudes. I have drawn through the observations the straight line which most nearly represents this change of angular velocity with latitude, and find, by the method of least squares, its equation to be

$$v=1{\cdot}158 \cos \chi^\circ \ (1+0{\cdot}00335\chi^\circ)$$

where v is the linear velocity in miles per second of any point in latitude χ° of the sun's reversing layer. This gives for the daily angular motion of any point on the reversing layer

$$\theta=794' \ (1+0{\cdot}00335\chi^\circ)$$

while from sun-spots, Carrington* obtains for the photosphere

$$\theta=865' \ (1-0{\cdot}191 \sin^2 \tfrac{1}{2}\chi^\circ)$$

As will be seen from Table I, the greatest irregularities in the value of $v'-v''$ occur between the latitudes 15° and 25°. May this not be connected with the fact that this is the region most favored with sun-spots, the *zone royale*?

Two neighboring lines† in the solar spectrum are often so differently affected by disturbances on the sun's surface as to indicate that the absorbing layers to which they respectively belong are situated at widely different heights.

That locus of absorption which is highest will, if we assume the sun a solid, rotate with the greatest equatorial velocity, and one might think that the values of $v'-v''$ for different lines should therefore arrange themselves in the same order as their corresponding metals in the sun's atmosphere. But with a tangential slit, as used in these measurements, it will be seen that the section of the solar sphere made by a plane passing through the slit and line of sight cuts each layer (for any given latitude) in a different heliocentric longitude; so that however

* Carrington: Observations on Solar Spots, p. 224. † Young: Sun, p. 100.

these different absorbing loci may differ in their distance from the center of the sun, the velocity of each portion of the section, *resolved in the line of sight*, will be the same.

It will not be surprising, therefore, if in the following table no connection is seen between the order of the velocities and the order in which the elements are generally supposed to be distributed* in the solar atmosphere.

TABLE II.

Line.	No. obs.	Substance.	$v'-v''$
E_2	26	Fe	2·289
"1474"	74	Helium + Fe	2·291
E_1 (double)	36	Fe + Ca	2·302
D_2	50	Na	2·320
D_1	106	Na	2·420
5173·838	55	Ti (?)†	2·590
5171·714	21	Fe	2·608
5166·3	8	Fe ‡	2·670

As a further possible test, I selected the "1474" line, of which the upper component is helium, and the lower, iron. It, if any, might be supposed to vary in width in passing from the eastern to the western limb of the sun. Accordingly one limb was brought upon the slit, and the micrometer run from one component to the other; the image was next shifted so that the other limb could be observed and the width again measured. The result, however, was entirely negative; not the slightest difference could be found. With this instrument a displacement as great as $\frac{1}{600}$ of the distance between D_1 and D_2 would have been detected with certainty. Hence we conclude that, if the locus of absorption for helium is different from that for iron, and if the one be drifting with reference to the other, the rate of this motion is less than one-third of a mile per second.

All attempts to measure the displacement of the helium line, D_3, resulted in failure, the line as seen in the fourth order not having sufficient sharpness to admit of any accuracy whatever.

In the absence of other evidence, the fair inference from these observations appears, therefore, to be that there is a lagging of the locus of absorption in the equatorial regions, and that the amount of this drift is approximately expressed by the following equation for the daily angular motion of any point whose heliocentric latitude is χ, expressed in degrees.

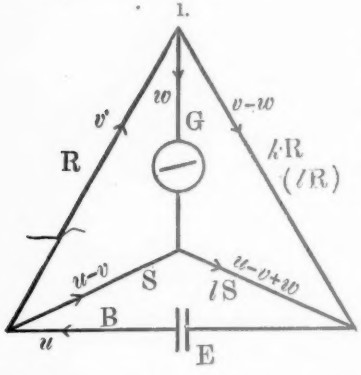
$$\theta = 794' \ (1 + 0{\cdot}00335\chi^{\circ}).$$

* For this distribution, see Lockyer's Chemistry of the Sun, pp. 161–169.

† Schellen's Spectrum Analysis, p. 598. ‡ Chemistry of Sun, p. 320.

Art. XIV.—*Theory of the Bolometer;* by Harry F. Reid, Ph.D.

The bolometer consists of a Wheatstone's bridge in which the resistances are first adjusted so that no current passes through the galvanometer. Two arms of the bridge are made of thin platinum strips; when one of these is exposed to the radiation of a hot body it grows hotter, increases in resistance, thus destroying the balance of the bridge and producing a deflection of the galvanometer needle, which measures the intensity of the radiation.*



Let u, v, w, be currents and R, kR, S, lS, G, B, be resistances in the Wheatstone's bridge, as in the diagram (fig. 1); and let E be the E. M. F. of the battery. By Kirchhoff's law for the distribution of currents we find

$$w=\frac{\mathrm{ERS}(k-l)}{\Delta},$$

where Δ is a function of the resistances in the various parts of the bridge.

The ordinary thermoelectric forces at the various junctions balance each other and do not affect the currents in the bridge. The thermoelectric forces due to the Peltier effect are very small and are quite negligible; when the four arms of the bridge are equal, their effect is merely to change slightly the total E. M. F.; we shall see later that this is unimportant.

We can replace E by its equivalent in terms of the current passing through the arm kR, which contains the exposable bolometer strip. (For convenience we shall designate the various arms of the bridge by their resistances). This current is essentially equal to the current v in the branch R when the bridge is balanced, since w is always very small in comparison to v.† We have

$$v=\mathrm{E}\frac{\mathrm{GS}(1+l)+\mathrm{S}l(\mathrm{R}+\mathrm{S})}{\Delta},$$

$$\therefore\quad w=\frac{v\mathrm{R}(k-l)}{\mathrm{G}(1+l)+l(\mathrm{K}+\mathrm{S})}$$

* For a detailed account of this instrument, see Proc. Am. Acad., 1881; this Journ. III, vol. xxi. p. 187, March, 1881.

† Professor Langley "On Hitherto Unrecognized Wave-lengths;" this Journ., III, vol. xxxii, Aug., 1886, foot note p. 94.

If δ is the deflection of the galvanometer needle, and D a constant depending on the form of the galvanometer, the period of the needle, etc., for small deflections

$$\delta = D\frac{vR(k-l)\sqrt{G}}{G(1+l)+l(R+S)}.$$

A particular bolometer will have its greatest sensitiveness when for a given value of $k-l$, and a given percentage probable error of observation, the deflection, δ, is greatest. This is obtained by giving proper values to D, G and v. The proper values of D and G must be determined independently of the intensity of the current, v; for changes in these values will merely alter the sensitiveness of the galvanometer, and will change in the same ratio the total deflection δ, and the irregular deflections of the needle, but will *not* change the percentage probable error of observation. D should be made as large as possible; i. e. we should select the best form of galvanometer, have the needle strongly magnetised and highly astatic and its period long. The best value to give G is $l(R+S)/(1+l)$. The current v must be increased to its greatest practical intensity; this limit, which is not at all well defined, is reached when the strip becomes sufficiently heated to set up *irregular* air currents, which cause fluctuations in its temperature and irregular movements of the galvanometer needle, thus increasing the probable error of observation.

Introducing the above value of G in the equation and writing $S=nR$ we get

$$\delta = D\frac{v\sqrt{R(k-l)}}{2\sqrt{(1+n).l(1+l)}}.$$

We have supposed the arm kR to contain the exposable strip of the bolometer. When this is screened from radiation and the bridge properly balanced, $k=l$, and the resistance of this arm is lR; when exposed to radiation let its resistance kR$=q l$R; then

$$\delta = \frac{D}{2\sqrt{(1+n)(1+l)}}v(q-1)\sqrt{l}R. \qquad (1)$$

lR is the resistance of the bolometer strip, and the wires connecting it to the bridge, when unexposed, and is of course a fixed quantity for any particular instrument. δ increases as l and n decrease. In order that the balance of the bridge should not be destroyed by the continued variation of the temperature of the room, it is found important to have the arms of the bridge, two and two, as nearly alike as possible; a second arm therefore is made of a platinum strip like the first and placed near it in the same case, but entirely covered up.

If the branch R contains this strip, $l=1$. What is the best value to give n? When n varies from 1 to 0, $1/\sqrt{1+n}$ varies from about 0·7 to 1; so that there is not a great advantage in making n less than 1; and there is a decided disadvantage. The currents in the branches R and S have the ratio $v/(u-v)=S/R=n$; the heat developed in R is v^2R; that in S is v^2R/n; if n is much less than unity, this becomes very large, the temperature of the branch S is raised too high and irregular movements of the needle are produced. If, on the other hand, the branch lS contain the covered strip, $n=1$; the heat developed in R and lR have the ratio $R/lR=1/l$; reasoning as above we conclude that in this case the most desirable value of l is unity.

To summarize: the bridge should be so arranged that $l=n=1$; the galvanometer resistance G should equal that of the bolometer strip R; B and E have disappeared from the equation; their actual values are therefore unimportant so long as v is fixed. This is applicable to the case in which we wish our instrument to have its greatest sensitiveness. If the quantity of radiant heat to be measured is so great that this is not desired we can diminish the sensitiveness by decreasing v or D or by adding a resistance to the galvanometer branch; it will usually be found advisable to change the first two quantities.

Let us now consider the strip itself. As the intensity of the current v is limited by the excess of temperature over that of the surrounding air to which we can raise the bolometer strip without producing inconvenient movements of the galvanometer needle, it will be convenient to replace v by its equivalent in terms of this excess of temperature. Let i be the ratio of the resistance of the exposed part of the strip to that of the whole arm in which the strip is; let t_0 be the temperature of the air and the enclosure surrounding the strip; t_1, the temperature of the strip when the current v is passing through it; $m'(t_1-t_0)$ and $m''(t_1-t_0)$ the loss of heat by radiation and convection per unit time per unit area of the blackened and metallic surfaces of the strip respectively (according to Newton's law of cooling, which is sufficiently accurate for the small changes in temperature under consideration); A′ and A″, the areas of these surfaces. We here suppose only a part of the strip to be blackened. The temperature of the strip will be constant when the amount of heat generated by the current equals the amount lost from the surface and by conduction, C_1; i. e. when

$$v^2iR=(A'm'+A''m'')(t_1-t_0)+C_1.$$

Putting the value of v derived from this equation in eq. (1), we find, writing $l=n=1$,

$$\delta=\frac{D}{4}(q-1)\frac{\sqrt{(A'm'+A''m'')(t_1-t_0)+C_1}}{\sqrt{i}}. \qquad (2)$$

q is the ratio of the resistance of the arm kR, when the strips are exposed to radiation (their temperature then being t_2), to their resistance when screened from radiation (their temperature then being t_1). According to Matthiessen's researches we have, for small changes in temperature,

$$q\mathrm{R}=\mathrm{R}+\alpha(t_2-t_1)i\mathrm{R}$$

$$\therefore \quad q-1=\alpha i(t_2-t_1).*$$

We may express (t_2-t_1) in terms of the quantities of heat absorbed and given off by the strip. When the strip is exposed to the radiation from a hot body, the heat falling on it is increased; we may, for convenience, consider that this latter radiation falls on the strip in parallel rays, as it approximately does. Let H be the increase of radiant heat passing unit area at right angles to the direction of propagation in unit time.

2.

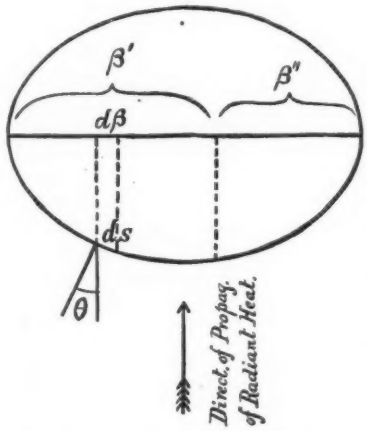


Fig. 2 represents the cross section of the strip; if λ is its length,† λds an element of the surface, θ the angle made by the normal to the surface with the direction of propagation of the radiation from the hot body; then H cos $\theta\lambda ds$ will be the increase of heat falling on the element λds; if a' and a'' are the average coefficients of absorption for the different angles of incidence actually occurring, of the blackened and metallic surfaces of the strip respectively, the heat absorbed by the strip in unit time will be $a'\mathrm{H}\lambda\int\cos\theta ds+a''\mathrm{H}\lambda\int\cos\theta ds$, where the two integrals are to be taken respectively over the blackened and metallic portions of the strip, which are exposed to radiation from the hot body. If β is the breadth of the strip, $\cos\theta ds=d\beta$, and the expression above becomes $a'\mathrm{H}\lambda\beta'+a''\mathrm{H}\lambda\beta''$; $\lambda\beta'$ and $\lambda\beta''$ are the projection as shown in fig. 2 of the blackened and metallic parts respectively of the front surface of the strip.

* α is not the coefficient determined by Matthiessen but can be readily calculated from his results.

† The bolometer strip is usually made of a number of narrow strips placed side by side and connected in series. We look upon it as consisting of a single strip bent back and forth; λ and $\beta'+\beta''$ are the length and breadth the exposable part would have if it were straightened out.

The temperature of the strip will be constant when the heat developed by the current plus the heat absorbed equals that lost by radiation and convection plus that lost by conduction, C_2; i. e. when

$$(A'm'+A''m'')(t_1-t_0)+C_1+a'H\lambda\beta'+a''H\lambda\beta''= (A'm'+A''m'')(t_2-t_0)+C_2;$$

$$\therefore\ t_2-t_0=\frac{(A'm'+A''m'')(t_1-t_0)+H\lambda(a'\beta'+a''\beta'')+C_1-C_2}{A'm'+A''m''}$$

and

$$q-1=\alpha i(t_2-t_1)=\alpha i\{(t_2-t_0)-(t_1-t_0)\}= \frac{\alpha i\{H\lambda(a'\beta'+a''\beta'')+C_1-C_2\}}{A'm'+A''m''}.$$

Introducing this value in eq. (2) we obtain

$$\delta=\frac{D\alpha\{H\lambda(a'\beta'+a''\beta'')+C_1-C_2\}\sqrt{i(t_1-t_0)}}{4\sqrt{A'm'+A''m''}}. \qquad (3)$$

$H\lambda(a'\beta'+a''\beta'')$ is the quantity of radiant heat absorbed by the strip; a' and a'' will be greatest when every element of the exposed surface of the strip is at right angles to the direction of propagation of the radiant heat; i. e. when the front surface of the strip is flat. $A'm'+A''m''$ is the heat lost from the whole surface of the strip in unit time when its temperature is one degree higher than that of the surrounding air and case. Other quantities remaining the same, this will be smaller and δ larger as $A'+A''$, the whole surface of the strip is smaller. C_1 and C_2 are smaller, the smaller the cross section of the strip. The less metal in the strip for a given exposed surface the more rapidly will it reach its temperature equilibrium when exposed to radiation. All these considerations show that it is best to make the strip very thin.

If the strip is so thin that a further decrease in its thickness would only diminish the amount of heat given off by it by a small fraction of this amount, it does not appear that any advantage would be gained by making it thinner. In the case of a strip 1^{mm} wide the limit is probably fully reached when the thickness* is $0{\cdot}01^{mm}$.

Let us now determine how much of the strip should be blackened. There are but three practical cases:

I. None of the strip blackened.

II. The whole surface blackened.

III. The front surface only blackened.

Referring to eq. (3) we see we need only consider the term†

$$\frac{\lambda(a'\beta'+a''\beta'')}{\sqrt{A'm'+A''m''}}.$$

* In Professor Langley's instruments the thickness lies between $0{\cdot}01^{mm}$ and $0{\cdot}001^{mm}$. See his paper "On Hitherto unrecog. Wave-lengths," cited above.

† We suppose the strip to be thin enough to allow us to neglect C_1 and C_2.

Write $\beta'+\beta''=\beta$; our three cases give:

I. $A'=\beta'=0$; $\beta''=\beta$; $A''=2\lambda\beta$;

and $$\delta_1 \propto \frac{a''\sqrt{\lambda\beta}}{\sqrt{2m''}}.$$

II. $A''=\beta''=0$; $\beta'=\beta$; $A'=2\lambda\beta$;

and $$\delta_2 \propto \frac{a'\sqrt{\lambda\beta}}{\sqrt{2m'}}.$$

III. $\beta''=0$; $\beta'=\beta$; $A'=A''=\lambda\beta$;

and $$\delta_3 \propto \frac{a'\sqrt{\lambda\beta}}{\sqrt{m'+m''}}.$$

Suppose a black body, with coefficients of absorption and emission, a' and m', to be placed in a stream of radiant heat of intensity H, its rise in temperature will be given by the expression $(t_1-t_0)=Ha'/2m'$; if the same body should have a bright surface with coefficients a'' and m'', its rise in temperature would be $[t_1-t_0]=Ha''/2m''$. Experiments with blackened and unblackened thermometers show that $[t_1-t_0]<(t_1-t_0)$; $\therefore\ a''/m''<a'/m'$; we also know that $a''<a'$, and $m''<m'$; we see therefore that $\delta_1<\delta_2<\delta_3$.

The eq. (3) can now be written

$$\delta=\frac{D\alpha HM}{4}\sqrt{i\lambda\beta(t_1-t_0)}; \qquad (4)$$

where M stands for $a''/\sqrt{2m''}$, $a'/\sqrt{2m'}$ or $a'/\sqrt{m'+m''}$, according as our strip belongs to case I, II or III.

In this expression for δ, D depends for its value on the form of the galvanometer, etc., as already noticed; α is ratio of the increase in resistance of platinum for one degree change of temperature above t_0, to its resistance at temperature t_0. Matthiessen found that this coefficient did not vary much for different metals. H is the intensity of the radiation to be measured. M has its greatest value when the front of the strip is very black and the back very bright; i can be given its greatest value by having the largest possible part of the strip exposable, and making the resistance of the rest of the branch kR very small. Since the resistance of the strip does not enter the equation, it is of no importance so long as the four arms of the bridge and the galvanometer all have the same resistance; but this should not be so small as to decrease materially the value of i, or to make the galvanometer connections an appreciable fraction of the resistance in the galvanometer branch. λ and β only occur multiplied together and under the radical sign; other things being equal δ varies as the square root of the exposable area of the strip; for a given

area it does not matter then whether the strip be made of a single broad piece of platinum or of several narrow pieces arranged side by side and connected in series. This however is subject to the limitations mentioned in regard to the resistance of the strip. The thickness of the strip does not occur in the expression above; we have supposed the strip flat and so thin that the edges are only a very small fraction of the surface, and the heat lost by conduction negligable; as long as these are true, the actual thickness of the strip is unimportant; (t_1-t_0) is the increase in the temperature of the strip above the case due to the current passing through it; for a particular bolometer it is proportional to the square of the current. It is this quantity most probably which regulates the strength of current that can be used.* If we had two bolometers which were identical in all respects except in the thickness and blackening of the strips, we could apparently use currents in them respectively strong enough to give the same value of (t_1-t_0); and if we made M the same for the two instruments, the deflection produced on subjecting them to the same source of radiation would be equal. The relative values of t_1-t_0 for different bolometers can only be determined by experiment; perhaps no great error would be made if we supposed them equal for instruments which do not differ greatly in the exposed area of their strips.

ART. XV.—*Are there Deep-Sea Medusæ?* by J. WALTER FEWKES.

IN a report on the Medusæ collected by the "Albatross" in 1883–84† I have already considered the question whether there are zones of medusan life in the depths of the sea. I have not, however, from the nature of that paper, written all that may be said, even in the present condition of our knowledge of the facts bearing upon it. It is hoped that the present paper will, at least, point out the great interest attached to a scientific answer to the question which is taken as the title of this communication.

A study of the fauna of the deep sea is of comparatively

* It is possible that the total quantity of heat generated in the strip by the current and communicated to the air and sides of the case may effect the limiting value of the current intensity. If so this would be an additional reason for making the strip thin.

† Report on the Medusæ collected by the U. S. Fish Commission Steamer "Albatross" in the region of the Gulf Stream, in 1883–4. *Annual Report Com. Fish and Fisheries*, 1884, pp. 927–977, Plates I–X, 1886. Many of the ideas here presented are also noticed in this paper.

modern growth. It is barely thirty years ago that naturalists almost universally believed the abysses of the ocean to be deserts as far as life is concerned. Deep-sea exploration has, however, not only revealed the fact that the ocean bed at great depths is peopled by a rich and varied fauna, but also that the animals which constitute that fauna are peculiar and markedly different from those found in shallow waters.

It would seem a most extraordinary exception, if after the floor of the ocean at great depths had been found to be inhabited, the fathoms on fathoms of water through which the sounding weight passes to reach those depths are destitute of life. In mid-ocean, where there is a highly varied nomadic life upon the surface and where the dredge has brought up from the ocean bed a characteristic assemblage of animals, are we to suppose that between these places there is not a representative fauna, or must we conclude that after we sink a few fathoms below the surface, life ceases, and that it is not until we come to the floor of the ocean that life again appears? If between these two limits there is a fauna, is that fauna the same as that found at the surface, or is it characteristic? Can the animals which compose it be circumscribed in bathymetrical zones out of which they cannot pass with impunity? Do we, in short, have in the nomadic oceanic life a change of fauna as we sink below the surface?

Naturalists have been led to suppose that since we find peculiar modifications in animals living upon the sea bottom at great depths, we should necessarily look for the same variation among nomadic animals at intermediate depths. It would then seem probable that there are bathymetrical zones for free-swimming animals, and that these animals are characteristic as compared with others which live at the surface. An investigation of the character of this fauna, if such there be, has an interest to the evolutionist, for it might be supposed to acquaint him with facts bearing on the general characters of the ancestors of certain genera of surface life.

I can imagine few places on the earth's surface where the uniformity of physical conditions is greater than in the depths of the sea. I do not mean, as might be supposed, necessarily on the floor of the ocean, but at the depth of say one thousand fathoms separated from the ocean bed by a wall of water of the same depth. Here, if anywhere, we may look for uniformity of conditions and if environment has anything to do with modifications in the generic forms of animal life, here we can expect to discover animals which preserve ancestral features. On the surface of the ocean there are changes of temperature, and of light, and climatic variations; at the floor of the ocean there may be reactions of the interior of the earth upon its

crust, perhaps lava flows or geological oscillations;* but midway between these two places, equally removed from both, disturbing causes only rarely penetrate and conditions remain more constant year by year. Can we not expect to find here a corresponding uniformity in the fauna as compared either with the highly organized animals of the surface or those of the depths of the ocean? Is that fauna more uniform than any other in the ocean?

No group of animals is better suited for a study of the questions which suggest themselves concerning the bathymetrical zones of characteristic animals, free-swimming at different depths in the ocean, than the medusæ. The group is a large and very variable one. It is confined, with but few exceptions, to the ocean. Moreover it is probable that its ancestors were oceanic animals. No group of marine animals presents fewer difficulties in studying the questions which we have stated than this.

It was with the impetus of a new enthusiasm for the study of these questions that I undertook, by the advice of Prof. Verrill, the examination of the rich collections of deep sea medusæ made in the Gulf Stream by the "Albatross." It seemed to me that the examination revealed much of general scientific interest.

I shall not consider in this discussion the Hydroida, as the members of this group are for the most part attached to the ground, and the problems connected with them are the same as those which pertain to all deep-sea animals attached or partially living on the ocean bed. We shall also pass by, in silence, the Ctenophora, no genus of which has yet been ascribed to the deep-sea. I propose to consider a few of those jelly-fishes which are known as the *Acraspeda* and incidentally the *Siphonophora*.

The history of the study of the deep-sea medusæ belonging to these divisions is a very brief one. In many of the monographs on these groups we have isolated mentions of medusæ which are ascribed to the deep-sea. The jelly-fishes thus mentioned were commonly washed into shallow water by ocean currents, by storms or unusual events in the ocean, and the depths at which they were supposed to live could only be conjectural. The specimens themselves were, for the most part, in a mutilated condition.

The first and only paper on the Siphonophora of the deep-sea is by Prof. Studer,† who describes new species and genera of these animals which were found twisted on ropes and wires

* Such changes might take place even if the oceans have practically been the same in past geologic times as at present.

† Zeitschrift für Wissenschaftliche Zoologie, vol. xxi.

used in deep-sea dredging and sounding. All of these are closely related to a genus called *Rhizophysa*, which is itself allied to a medusa called *Physalia*, or the "Portuguese-man-of-war," which habitually floats on the surface of the ocean.

The most important work which we have on the Acraspeda (the ordinary jelly-fishes found in shallow waters), of the deep-seas, is a report* by Prof. E. Hæckel on a collection made by H. M. S. "Challenger." No one has done more than he to elucidate the structure of the jelly-fishes, and he stands without an equal in his contributions to a knowledge of the deep-sea members of the group. This work of Hæckel is, up to the present, the greatest contribution of any naturalist to the study of the medusan representatives of the deep-sea fauna.

If space permitted, one or two other smaller contributions might be mentioned, but these two works are the most important additions to our knowledge of the deep-sea Acraspeda and Siphonophora.

We have no complete account of the deep-sea jelly-fishes of the Gulf Stream. That great body of water, which sweeps along our coast from the straits of Florida, northward, bears a nomadic life, of the wealth of which no one has yet a just conception. Those who have studied the stream in all latitudes have spoken of this fact, and one needs but lower a drag net in its waters for a few minutes to become convinced of its truth. The surface of the Gulf Stream has been but partially explored, the inhabitants of its depths, except on the very bed, are unknown.

The means which have been used for the collecting of animals from intermediate depths are not all that could be wished for. There is a call for greater refinement in this kind of collecting. A common way of obtaining this life is as follows. The dredge, trawl or drag-net drawn up from a great depth is found to bring with it a medusa. That medusa is recorded from the depth of the trawl. What then is the possibility that it entered the dredge on the passage up through the water? I think every one will acknowledge that the possibility is very great, and that the medusa may or may not have come from the deep-sea. A drag-net attached to a dredge-rope or wire is sometimes lowered to a certain depth and then drawn up. Here also we may ask how is it known that the medusa found in the net entered it at the recorded depth? A Siphonophore clinging to a wire rope used in sounding or dredging may or may not, as shown by A. Agassiz, have become twisted upon it at the depth at which the animal appears to be found when

* Report on the Deep-Sea Medusæ dredged by H. M. S. "Challenger" during the years 1873–76. Report on the Scientific Results of the voyage of H. M. S. Challenger during the years 1873–76, vol. iv, No. II.

brought on deck. "In most cases," writes Prof. Verrill, "it is impossible to say whether the novel forms of medusæ taken in the trawl and trawl wings are inhabitants of the bottom waters or the surface, or of intermediate depths. Eventually those that belong to the surface fauna will doubtless be taken in the surface-nets, but this will require much more extensive collecting of the surface animals than has yet been attempted."

It will thus be seen that the means of determining the depth at which the collecting of free oceanic animals takes place are too imperfect for any accurate knowledge of the bathymetrical limits of so-called deep-sea medusæ. We are in fact on the very threshold of this kind of research, and what is now most needed, in the study of bathymetrical zones of marine life, are improvements in methods of collecting at any depth, so that we can tell exactly at what distance below the surface a nomadic animal is captured. Devices have been suggested, one of which, the so-called "Gravitating Trap," of Lieut. Sigsbee, has been described in the Bulletin of the Museum of Comparative Zoölogy at Cambridge. I am not aware how extensively this apparatus, or others of similar kind, have been used by those who are in charge of deep-sea exploration, or whether it has been sufficiently tried to test its usefulness * If medusæ were always as abundant at great depths as they sometimes are at the surface, a device might easily be invented for the successful capture of at least a few specimens. It seems more probable that medusæ are not common enough to warrant one in supposing them very numerous, and the difficulty in their capture thus becomes greater, rendering it necessary that some modification of the gravitating trap be invented.†

In a letter to Mr. C. P. Patterson (Bull. Mus. Comp. Zoöl., vol. vi, No. 8) Mr. A. Agassiz calls attention to the uncertain methods adopted for ascertaining at what depths free-swimming animals live, and from experiments with the "Sigsbee Trap" concludes (p. 153), while he does not deny that there are certain genera of deep-sea medusæ, that "The above experiments appear to prove conclusively that the surface fauna of the sea is really limited to a comparatively narrow belt in depth, and that there is no intermediate belt, so to speak, of animal

* Results of Explorations made by the Steamer Albatross off the Northern coast of the United States in 1883. *Annual Report Com. Fish and Fisheries*, 1883.

† The small amount of water which enters the Sigsbee gravitating trap is one great objection to it. Negative results with this apparatus do not necessarily show that life does not exist at the depth at which the door is opened, and the instrument does not collect from a large enough area for a successful determination of the abundance of life which it is intended to capture. From what has been published, and statements of those engaged in deep-sea exploration, I am led to suppose that the "Sigsbee Gravitating Trap" has given only negative data in regard to the problem of the existence of characteristic nomadic life in intermediate depths of the sea.

life, between those living on the bottom or close to it and the surface fauna."

This statement from such a high authority in the study of marine zoology would seem to effectually crush any murmur of belief in intermediate zones in the distribution of oceanic forms of life. While I have the highest respect for this view, I cannot help entertaining an opinion that more observations are necessary before we can accept the proposition that there are not characteristic belts of pelagic animals at different depths.

With the question whether the recorded depths at which the Medusæ which we shall consider are found, are accurate or not, we cannot deal. Indeed, at this stage of this kind of deep-sea exploration, an examination of these methods would be foreign to the purposes of this paper. We take the data as given by the collector and at present leave the improvement of the collecting apparatus to others.

Can we not approach this subject from another side? Are there any characteristics in the Medusæ themselves which show that they are preëminently fitted to live at the depths or approximate depths from which they are reported? Has their habitat left any traces in the modification of their anatomy? Has the uniformity of conditions in their habitat led to a corresponding simplicity in their structure and are they nearer the ancestral forms than others with a more varied environment? An account of the singular structure of one or two typical genera may help us to answer this question or at all events present certain facts which bear upon it. Let us therefore for illustration consider one or two representatives of the Acraspeda and Siphonophora discovered by the Albatross in the depths of the Gulf Stream.

Everyone familiar with the anatomical structure of the Siphonophores will recognize how difficult it is to find in those genera like *Rhizophysa* anything to point to an adaptation to a deep-sea life. The Albatross has discovered new Physophores closely allied to *Rhizophysa*, one of which, *Petrophysa*, reaches the enormous size of twenty feet in length in alcohol. The float of this animal is larger than that of any true Siphonophore except *Physalia*. The large size of the float in these Physophores would seem an effective argument against their adaptation to a life in deep water, especially as their nearest ally, *Physalia*, is preëminently a surface form.

It is extremely difficult to gather from the structure of the known Siphonophora ascribed to the deep-sea anything to indicate an adaptation to such a life. The group can afford little satisfaction in our answer to the question of whether there is a nomadic deep-sea life or not.

The nature of the argument for the existence of medusan life in bathymetrical zones may be best illustrated by considering a few examples of the Acraspeda. These are not the only instances which might be chosen and possibly are not the best. They are thought to be as suggestive as any among the Acraspeda which have been ascribed to great depths.

One of the most characteristic families of Acraspeda is called the *Collaspidæ*. The family is supposed to belong to the deep-sea and is represented by two genera, *Atolla* and *Collaspis*, which differ from each other rather obscurely in the regular or irregular arrangement of the sexual glands. It is a question whether we have more than specific differences in the features which have been pointed out by Hæckel as separating the two.

Up to the present the genus *Atolla* is represented by a single species collected by the Challenger (*A. Wyvillii* Hæck.) and two species from the Gulf Stream (*A. Bairdii* and *A. Verrillii* Fewkes).

The structure of *Atolla* is thought to be more primitive than the ordinary inshore genera, *Cyanea* and *Aurelia*. It is so characteristic that I repeat from my paper on the anatomy of this genus, a condensed notice of some peculiarities.*

If we compare *Atolla* with our common surface medusæ, as *Aurelia*, we notice many marked peculiarities.

In the former we have a coronal furrow, which is not represented in *Aurelia* although found in a well known surface medusa (*Periphylla*). We have in *Atolla* a variable number (generally twenty-two) of sense-bodies or peduncles of the same. In *Aurelia* we have always eight sense-bodies. The coronal muscle is peculiar to *Atolla*.

The sense-bodies of *Atolla* are spoken of by Hæckel as rudimentary, and it is supposed that we have in a deep-sea medusa an adaptation for a life in the depths into which the light never

* The umbrella when seen from the upper side is found to be divided by a deep ring-shaped groove into a central and peripheral region. The groove is called the coronal fossa, the central region, the *discus centralis*, and the periphery the corona. The corona is formed of a number of wedge-shaped, gelatinous blocks, joined together and bearing on their outer rim, alternately, tentacles and sense organs. These gelatinous blocks are designated by the term socle, taken from architectural nomenclature, and are of two kinds: those which bear the tentacles called the tentacular socles, and those which carry the sense-bodies (if such exist) the socles of the sense-bodies. The socles of the sense-bodies bear two thin flaps called the marginal lappets. On the under side of the disk we have, below the corona, a large ring-shaped muscle called the coronal muscle, which is highly characteristic and larger in this genus than in any other known medusa. Axially to this muscle there is a zone formed of eight kidney-shaped sexual glands, and a simple mouth, which opens into a bag-shaped stomach. In the interior of the body there is a circular cavity filling the central disk, which opens by four orifices into a ring-shaped sinus which lie in the gelatinous body of the corona. From the outer edge of this ring-shaped sinus simple, unbranched, peripheral tubes extend through the bell-substance, passing into the cavities of the tentacles and rudimentary marginal sense-bodies.

penetrates. We may have here, what we so often find in deep-sea animals, a reduction in the size and efficiency of the special organ of sense to fit the medusa for the conditions under which it must live in great depths. Stated in a startling way, we might speak of *Atolla* as a blind medusa. This statement would hardly be justifiable and we can at present go no further than to say that the special sense-bodies of sight * are supposed to be rudimentary. It must however be borne in mind that nowhere among Acraspeda do we have so many, twenty-two, sense-bodies as here. In some specimens there are twenty-eight sense-bodies in this genus.

It is extraordinary that one of the known species of *Atolla*, (*A. Wyvillii* Hæck.), comes from the Antarctic Ocean, while our two species were both from the *warm* (?) water of the Gulf Stream. In the southern hemisphere its lowest limit is about 2000 fathoms, while north of the equator it comes from the surface or within a few hundred fathoms.

Among the medusæ collected by Lieut. Greely in the icy waters of Lady Franklin Bay, is an interesting jelly-fish allied to *Atolla*. This genus (*Nauphanta*) has been found but once before and then by the naturalists of the Challenger in the neighborhood of the island of Tristan d'Acunha in the South Atlantic. In the latter locality it is recorded from about 1500 fathoms, while in Lady Franklin Bay it is found on the surface. From several differences in these two specimens, those from the Arctic and those from the South Atlantic, I have supposed the boreal form to be new and have called it by the specific name *polaris*.† The Challenger specimens were placed under a new genus called by Hæckel, *Nauphanta*.‡

Before we consider the relationship between *Atolla*, *Nauphanta* and other related medusæ, ascribed to the deep-sea, let me mention another new medusa collected by the Albatross in the Gulf Stream. The genus *Nauphantopsis*, is of interesting affinities, since it has the same central disk as *Nauphanta* and

* Whether the "eye" of the jelly-fish can distinguish form or not has not been demonstrated. Simple experiments made by passing rays of light through dishes in which they are confined, or the simple fact that they almost always congregate on the illuminated side of the same, are not conclusive to me that they distinguish *form*. Experiments with sensitive plates to show the depths to which light penetrates the water are most suggestive in this connection. It seems pertinent to the whole inquiry to ask whether looked at from the physical side there are not rays of light of such a nature that the vertebrate eye is not able to perceive them, but which may act upon the visual organs of other animals.

† *Nauphanta polaris* has a central disk as in *Atolla*, a coronal fossa, and a corona, which, however, is formed of sixteen socles, eight of which bear tentacles, tentacular socles, and eight sense-bodies. The outlines of these socles is more clearly marked than in *Atolla* on the upper surface of the corona, which they form, on account of the deep sculpture which separates them.

‡ The name Nauphanta was preoccupied in 1879, when applied to this Medusa, having been given to a worm in 1864.

Atolla, the same coronal fossa and coronal socles. It is most closely allied to *Nauphanta* but has thirty-two socles instead of sixteen, eight sense-bodies (?) and twenty-four tentacles.* These tentacles are therefore arranged in threes, each series of three alternating with eight sense-bodies.—All with gelatinous socles.

It is easy to interpret the three deep-sea Acraspeda, *Atolla*, *Nauphanta*, and *Nauphantopsis*. At first sight they closely resemble gigantic young *Aurelia* or *Cyanea* in a stage which is called the ephyra. This is especially true of *Nauphanta*, which has the same number and arrangement of tentacles as the young *Cyanea* or *Aurelia* in the ephyra stage. It is so close, in fact, that at first sight they seem identical. In *Nauphanta* we have mature ovaries, and this would seem to indicate the adult form. The existence, however, of ova, and a sexual maturity is by no means an indication of the acquisition of the adult form among medusæ, and many instances might be mentioned of a jelly-fish with mature ova even before embryonic appendages have been dropped. There is nothing then to prove that *Nauphanta* is not the young of some other medusa, and on the other hand there is no proof that it is not an adult. If it is an adult, it is a mature medusa with likeness to embryonic conditions of other medusæ. It would then be nearer the ancestral form of Acraspeda than any of the more common medusæ like *Cyanea* and *Aurelia*.

At first study, I was inclined to regard *Atolla* as a giant ephyra of some unknown medusa. Its affinities are certainly very close to *Nauphanta* and through the latter genus it is connected with ephyra, the young of *Cyanea*. We may therefore regard both these genera as embryonic in their structure and as close allies of the young of a higher jelly-fish. It is a most interesting fact that two genera with such marked characters are considered deep-sea genera. Exactly what the evolutionist would expect from the uniformity of conditions which exist in deep water, we find manifested in the simple anatomy of two of the more characteristic deep-sea genera of Acraspeda, a simplicity of structure of embryonic and therefore of ancestral nature. It is certainly strange that these two facts are associated. It is an extraordinary coinci-

* *Nauphantopsis* is an interesting genus in its relationship to the surface genus *Periphylla*, which has four sense-bodies and twelve tentacles in four series of three each. We likewise have in the same genus marked coronal socles, sixteen in number, while *Nauphantopsis* has thirty-two. *Nauphantopsis* then appears to be a connecting genus between *Nauphanta* and *Periphylla*. I believe we are justified in regarding *Nauphanta* as an adult, although when I first studied it I was strongly inclined to regard it an immature animal. It must be confessed that, with the exception that it has eight sense-bodies, while *Periphylla* has but four, there are strong resemblances between a young *Periphylla* and the genus *Nauphanta*.

dence if the deep water at which the medusæ were found and the embryonic affinities in their anatomy have not the relationship of Cause and Effect. The discovery of a *Nauphanta* in the icy waters of the Arctic,* while it shows that the genus may approach the surface when the temperature of the depth at which it lives becomes a surface temperature, would also indicate that the genus is not confined to the great depth at which it is reported from the South Atlantic. If *Nauphanta* cannot rise to the surface in the latitudes of Tristan d'Acunha, it may be that the elevation of temperature above its habitat keeps it at great depths. At the higher latitude of North Greenland, however, the cold zone, in which *Nauphanta* lives in the South Atlantic, is about the surface temperature. Here, then, as far as thermal conditions go, the medusa can rise to the surface. We here encounter what I believe will be found to be an influence of more important character in the modification of medusan life at great depths, than the depth of water itself. Medusæ are sensitive to changes of temperature in the ocean; so sensitive in fact, that for many genera the line of demarkation between warm and cold oceanic currents are often dead lines to these delicate creatures. It is well-known that certain genera can be frozen without being killed by the change, and that medusæ suffer less from a diminution in temperature than from an elevation of the same. This is particularly true of those genera like *Aurelia*, *Sarsia* and others which habitually inhabit cold water. A temperature of +70° F., is fatal to them, while many tropical forms will easily live even in higher temperatures. Temperature in the ocean has drawn invisible lines in the distribution of medusæ in depth as well as latitude, and it is at present very difficult to separate this cause from that of pressure in the bathymetrical limits of the jelly-fishes. The poverty of our knowledge of the ranges of temperatures which jelly-fishes can endure is too great to admit of any generalizations of value on this question. Still there are no facts of more vital importance in the discussion of the question of whether there are deep-sea Acraspeda than those which bring information of the thermal limits at which the medusæ can live.

It would be profitable, if space permitted, to consider other genera of Acraspeda made known by the Albatross, in their bearings on the question which is the title of this paper. The three genera already considered present us the strongest arguments which can be found in the modification of external and internal anatomy, as indicative of a deep-sea habitat.

* Report on the Medusæ collected by the Lady Franklin Bay Expedition, Lieut. A. W. Greely commanding. Appendix No. XI.

"Those Medusæ," writes Hæckel, "may be regarded with greater probability as permanent and characteristic inhabitants of the deep-sea, which have either adapted themselves by special modifications of organization to such a mode of life, or which give evidence by their primitive structure of a remote phylogenetic origin." He then enumerates those which he places in this category, among which are the two remarkable genera, *Atolla* and *Nauphanta*. "It is by no means certain," writes Hæckel, "that all the eighteen medusæ described below, (Report on Challenger Medusæ) are constant inhabitants of the deep-sea." We have discussed the argument drawn from two of the most characteristic of the Acraspeda, viz: *Atolla* and *Nauphanta*, and can readily subscribe to this statement as far as these are concerned.

The resemblance of *Nauphantopsis* and *Atolla* to Ephyra is believed to have a morphological significance; Ephyra is thought to be the ancestral form of the Acraspeda, and these so-called deep-sea medusæ still preserve the ancestral form with small modifications, except in size, repetition of organs, and certain other characters. Of the development of *Atolla* or of the *Collaspidæ* we know nothing, and yet a knowledge of this subject is possibly to reveal the solution of important questions. If the mode of growth should prove to be a direct development without a *Scyphostoma*, it would certainly increase my belief that these medusæ somehow resemble the ancestral forms. I have already elsewhere shown that among the hydromedusæ with alternation of generations and those with a direct development, the latter method is normal while the former is a secondary modification. Among Acraspeda, also, the direct development of *Pelagia* is the ancestral method, while the formation of a Scyphostoma is a secondary modification. We should expect to find in *Atolla* a direct development, if it be an ancestral genus. From its mode of life in the high seas we should also expect the same.*

Abandoning, for the present, as insufficient, any evidence which might be adduced from the structure of the medusæ

* I believe the Lucernarians are degenerate adult Acraspeda, which have attached themselves to the bottom much in the same way as *Cassiopea frondosa* and become modified in consequence. While it may be said that they are homologous to the Scyphostoma stage, it is not thought that they are ancestral. They are in reality secondarily modified, for the ancestral method of development is direct, without an attached young, in Acraspeda, as in Craspedota.

While the primitive structure and relationship of *Atolla*, *Nauphanta*, and *Nauphantopsis* would seem to ally them closely to Ephyra and stamp them as less modified than such genera as *Cyanea*, in certain anatomical details, they might be regarded as higher even than the last mentioned. We cannot, consequently, draw from their simple relationship to an embryonic form, the conclusion that they have retained that likeness on account of the simpler conditions of deep-water habitat. Nor is the argument drawn from the supposed abortion of the sense-body conclusive, as far as these medusæ are concerned, although it looks plausible.

themselves and passing to the recorded facts in relation to bathymetrical distribution, we find no more satisfaction from this consideration. It would appear that the strongest arguments for the existence of nomadic deep-sea medusæ of the Acraspeda are found by Hæckel in the following genera.* The names in brackets are authorities for distribution.

1. Pectanthis: Surface (Hæckel).
2. Pectyllis: 200–600 fms. (Hæckel).
3. Pectis: 1260 fms. (Hæckel).
4. Cunarcha: "Possibly captured in drawing up the lead," (Hæckel).
5. Aeginura: "2150 fms. apparently" (Hæckel).
6. Periphylla: Surface (Fewkes).
7. Periphema: 1975 fms. (Hæckel).
8. Tesserantha: 2160 fms. (Hæckel).
9. Atolla: 2040 fms. (Hæckel), surface (Fewkes).
10. Nauphanta: 1425 fms. (Hæckel), surface (Fewkes).

Of the above genera the Albatross has collected many specimens of *Periphylla* and *Atolla* from the surface of the ocean. Greely collected a species of *Nauphanta* from the icy waters of the surface of Lady Franklin Bay; *Periphema* is so closely allied to *Periphylla* that we may well hesitate to accept its limitation to the great depth at which it is recorded (2160 fms.); *Pectyllis* is recorded from 200 to 600 fms. In the present use of the word deep-sea this genus can hardly be regarded as preëminently a deep-sea medusa. There remains† *Pectis* (1260 fms.) and *Tesserantha* (2160 fms.) as the only genera in the above list which can be regarded as purely deep-sea in their habitat. Each of these is described from *single* specimens and the former is closely allied to well-known surface genera. The foundation in observation for a belief in the existence of nomadic deep-sea medusæ, as far as recorded depths go, is certainly not all that might be desired.

Possibly a stronger argument for the existence of deep-sea Acraspeda may be drawn from the structure of the interesting free genus of Lucernaridæ (*Lucernaria bathyphila* Hæck.). This species is recorded from 540 fms. The fixed *Lucernariæ* are found in shallow water. The argument drawn from the

* Op. cit., Introduction, p. ii.

† *Cunarcha* was "possibly captured in drawing up the lead," and *Aeginura*, 2150 fms., "apparently."

As a bit of positive evidence that *Atolla* is a deep-sea medusa, Mr. Thomas Lee, who has seen the genus when collected, informed me, after I had shown him a specimen of *Atolla*, that he remembers it in deep-water trawls. In new collections made by the Albatross in 1885–86, *Atolla* in several instances is recorded from the "Surface;" and one of those described in the collections of 1883–84 is recorded from the Surface.

structure of the free Lucernarian would be stronger if the so-called attached species had been brought up from great depths, or if *Scyphostoma* had been reported from the ocean bed. It is suggested that those who have in charge the collecting of deep-sea animals, observe with care the contents of the dredges for attached *Scyphostoma* and Lucernarians, and it is particularly desirable, from a morphological standpoint, that the development of such genera as *Atolla* be known. If it can be shown that this and related medusæ have an indirect development, with an attached *Strobila* living in great depths, they may rightly be called deep-sea medusæ. A nomadic jelly-fish, limited in bathymetrical habitat, could best fulfill its conditions of life by having a direct development without attached larval conditions.

Why cannot we suppose that deep-sea medusæ can live at the surface and also at great depths? Why look for bathymetrical zones in the ocean for nomadic animals? The main reason seems to be the exceptional nature of such a wide distribution in places so widely separated in physical characteristics. It may be possible for a medusa to live equally well at the surface and under a pressure of 2000 fms. of water, and in the different temperatures of these two regions, but if they can endure these widely different conditions, they do not resemble other animals and their own relatives from the shallow waters. The logical inference from what is known of the differences between the facies of deep-sea animals on the ocean bottom and those from the littoral zone, would seem to be true of animals which are not fixed to the ground nor dependent upon it, viz: that there are bathymetric limits in the ocean, even to nomadic animals apparently as helpless as the medusæ.

In closing my short discussion of the question of deep-sea nomadic medusan life, it can be said that as far as the data thus far gathered goes, neither the recorded depths, nor the structure of the genera considered, demonstrates that we have a serial distribution of free medusæ in bathymetrical zones. While our present information is insufficient to answer the question, *it seems* to me that the case is much stronger than the arguments which can be advanced in its support. There is little doubt that medusan life has bathymetrical limitations. Our well-known surface medusæ probably cannot live at great depths, and their places are probably taken there by others; still, until there are more exact data bearing on this conclusion, it cannot be demonstrated to be true. What is now needed is, in the first place, an accurate determination of the depth at which medusæ of different genera are captured, and secondly a more accurate study of peculiarities of anatomy and development of those which are supposed to be thus lim-

ited in habitat. It is also equally necessary that the surface fauna should be better known for comparison. There are at present a few marine stations in the Mediterranean and North Atlantic, where the study of surface life is zealously prosecuted, but it is only when the Müllers' net has been used with equal zeal in the South Atlantic, the Indian ocean and Pacific, that we can have a basis to work upon. An exploring vessel on a cruise through these waters is not enough. It is a reconnaissance. There must be established permanent marine stations where the study will be carried on year after year for a long time in one locality.

OBITUARY.

FERDINAND V. HAYDEN.—Dr. Hayden, whose death is announced on page 88, of the January number of this Journal, was born in Westfield, Mass., in September, 1829. He was a graduate of Oberlin College, Ohio, and received the degree of Doctor of Medicine from the Medical School of Albany, N. Y., in 1853. He was surgeon in the army during the civil war; and after it, for seven years, he held the position of Professor of Mineralogy and Geology in the University of Pennsylvania.

But the larger part of his time from 1853 to the close of 1878, an interval of twenty-six years, was spent in Rocky Mountain exploration, in which his special work was geological; and through his labors and the investigations of those associated with him, a wide extent of territory, until then little studied, was examined geologically and topographically, coal beds were found and a new coal flora made known, new fossil mammals and other species in great numbers were collected and described, the stratigraphy and paleontology of the Cretaceous and Tertiary and the intermediate Laramie or Lignitic beds were well investigated, and the Yellowstone Geyser region brought to notice, explored and described with full illustrations.

Dr. Hayden's personal work consisted in a general geological reconnaissance of the regions visited, the collection of fossils, which was the chief object of the earlier expeditions, and the supervision and direction of the surveying parties. He was the first to make known the facts as to the vast Tertiary lake-areas of the summit region and eastern slopes of the Rocky Mountains, whence he drew the conclusion that the elevation of the mountains went on slowly through the whole Tertiary, commencing with the Laramie, which afforded some brackish water fossils.

His first two expeditions were made in 1853 and 1855, to the Bad Lands on White River, in Dakota,—that of 1853 at the expense of Professor James Hall. Large collections of remains of fossil mammals were brought home, besides numerous other species. His paleontological friend, Mr. F. B. Meek, was with

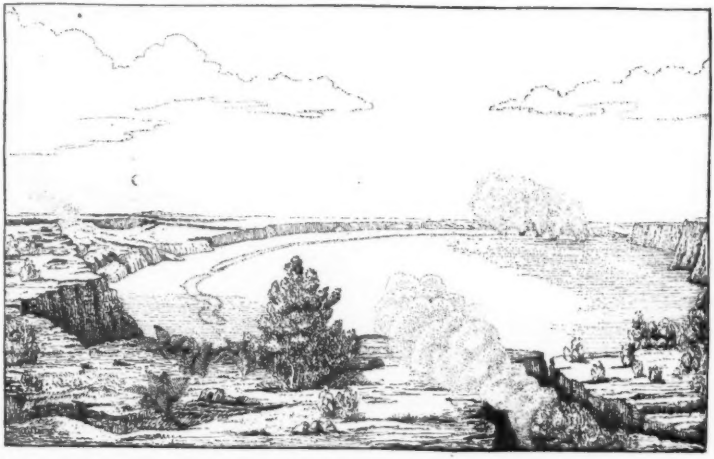
him! In 1857, he accompanied Lieut. G. K. Warren's expedition and made the discovery of the rich Niobrara Mammalian fauna, newer than the White River, and obtained a great number of specimens. In 1866 he was in the Bad Lands, making collections for the Academy of Natural Sciences of Philadelphia. The mammalian remains obtained in these various expeditions, along with those gathered by Dr. John Evans in 1849 and 1853, and Mr. Culbertson in 1850, were the material used by Dr. Leidy for his great work on the Extinct Fauna of Dakota and Nebraska (1869).

During 1859 and 1860, Dr. Hayden was connected, as geologist, with Capt. Raynold's expedition to the headwaters of the Yellowstone and Missouri. In 1867, after the civil war, the series of government expeditions under his charge was begun that continued through the consecutive years to the close of 1878. By these expeditions his explorations became extended over large parts of Nebraska, Dakota, Colorado, Utah, Wyoming, Montana, New Mexico and Kansas. The first appropriation was only $5,000; but the later were more liberal; and besides his regular corps, a number of other scientists sometimes accompanied the expedition. Mr. Meek was usually with him, and through him large numbers of invertebrate species of the Cretaceous, Tertiary, Jurassic and other formations were figured and described; and precision was thus given to the facts for success in laying down the subdivisions of these formations and mapping their distribution. After the death of Mr. Meek, in December, 1876, his department passed under the charge of Dr. C. A. White. Mr. L. Lesquereux investigated, figured and described the fossil plants of the Laramie and other formations. Dr. Cope joined the expeditions of 1872 and 1873, and afterward described the vertebrate fossils, collected in these and later years, in two quarto volumes. In 1877, the parties of exploration included the geologists Dr. C. A. White, Dr. A. C. Peale, Dr. F. M. Endlich, O. H. St. John, the accomplished artist Mr. W. H. Holmes, the topographical surveyors A. D. Wilson, G. R. Bechler, G. B. Chittenden, H. Gannett, the excellent photographer W. H. Jackson; and also Dr. S. H. Scudder and Mr. F. C. Bowditch of Cambridge, Dr. Leidy of Philadelphia, and the first botanists of England and America, Sir Joseph D. Hooker and Dr. Asa Gray.

The many volumes of the expedition in octavo and quarto, and the atlases, need not be here enumerated. Dr. Hayden had reason for feeling gratified with the great scientific results of the expeditions and his own earlier labors, and the wonderful developments made with regard to the ancient life of the continent, and the display of the country's resources and topographic features.

The office work of the expedition closed in June, 1879. Since then Dr. Hayden has lived in Philadelphia. He has had in course of preparation a final geological report on his expedition work; but what progress was made is unknown to us.

Dr. Hayden was a member of the National Academy of Sciences, and received various honors from academies abroad.



KILAUEA, IN 1864 (?). From a painting by Mr. Perry.

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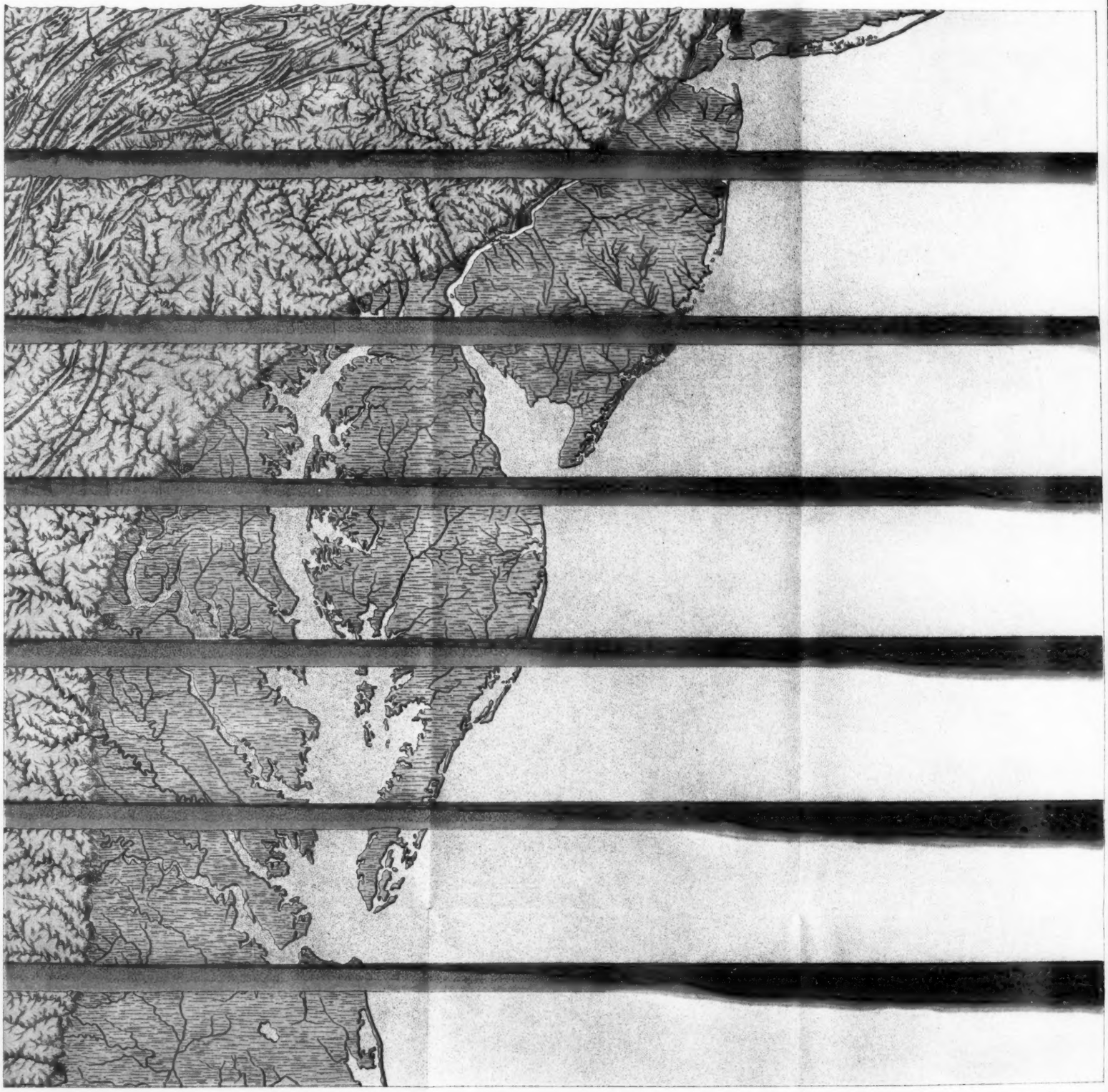

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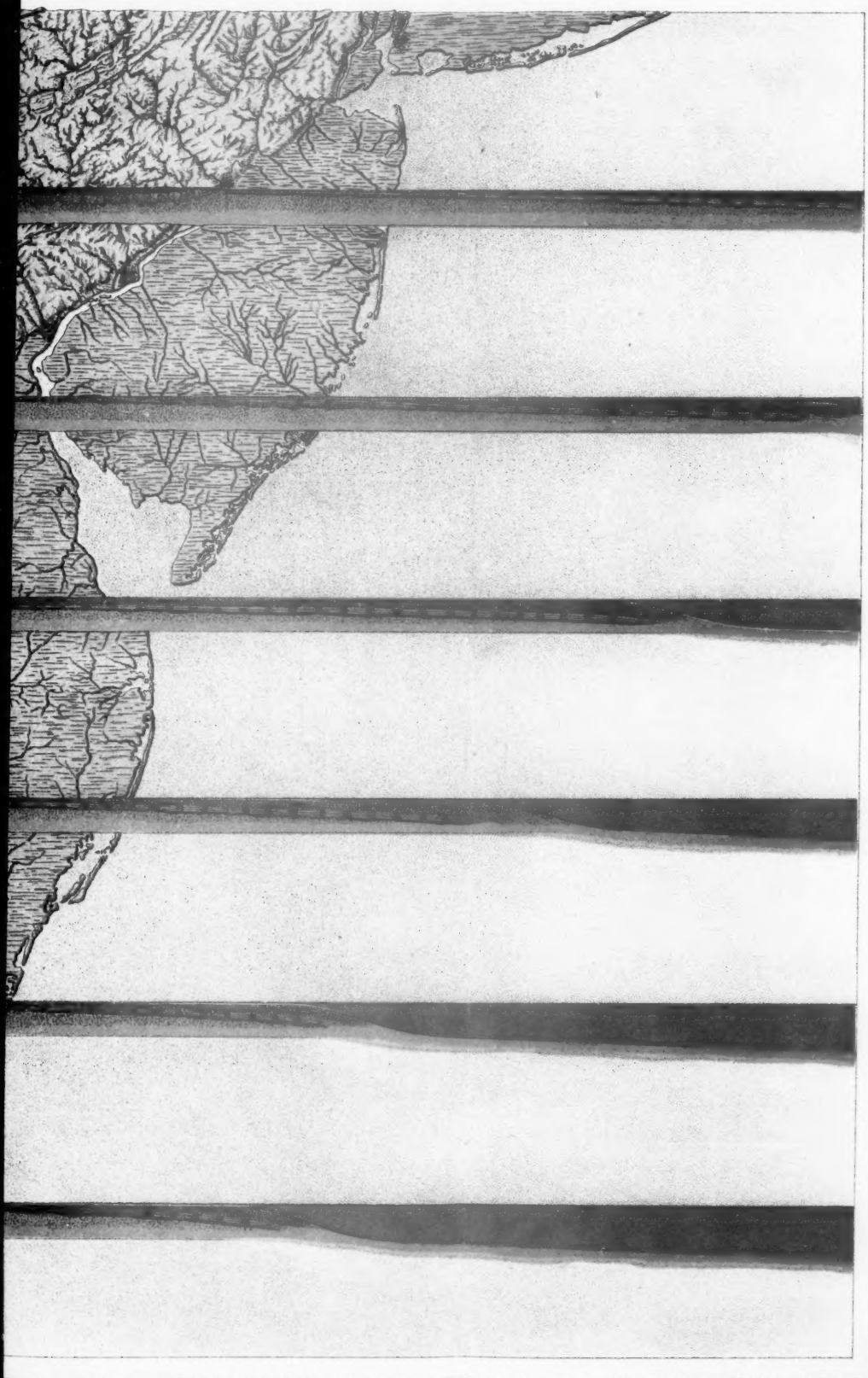

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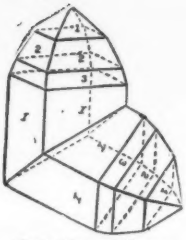

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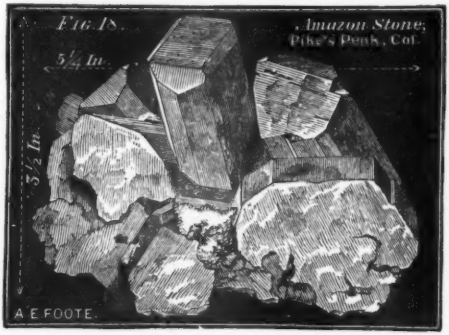

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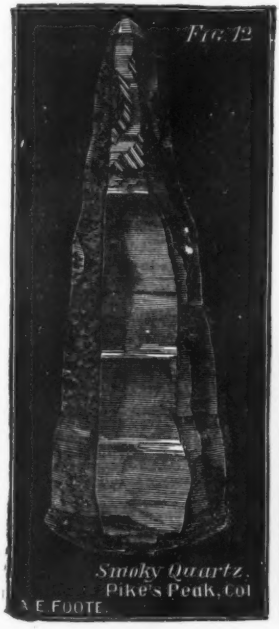

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